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Particle Tracking Model (PTM) in the SMS10: IV. Link to Coastal Modeling System

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the coupling between the Particle Tracking Model (PTM) and the Coastal Modeling System (CMS). It familiarizes users with the PTM-CMS coupling interface as implemented inside the Surface-water Modeling System Version 10 (SMS10). The steps necessary for preparing solutions of two-dimensional CMS-Flow and CMS-Wave models for input to the PTM are described, and two examples are given.

INTRODUCTION: The PTM computes the paths of sediment particles through a geometric domain as these particles interact with the computational environment within that domain. The computational environment includes the hydrodynamic flow, wave conditions, sediment data, and land boundary. The PTM accepts the domain and solutions defined by a CMS simulation for its calculations. This means that water surface elevations and currents calculated by CMS-Flow and wave information by CMS-Wave drive the PTM computations within the CMS domain defined by the CMS grid (origin, orientation, extents). The SMS includes tools to generate the additional information necessary to define the PTM environment, such as sediment bed data.

PARTICLE TRACKING MODEL (PTM): The PTM was developed jointly by the Coastal Inlets Research Program (CIRP) and the Dredging Operations and Environmental Research program. It calculates the fate and pathways of sediments and other waterborne particulates in coastal engineering and dredging operations in a Lagrangian modeling framework. The PTM simulates sediment movement in a flow field, including erosion, transport, settling, and deposition. In addition to predicting particle transport pathways and fate, the PTM produces maps of particle transport processes, such as mobility, which can be useful in interpreting sediment behavior. Time series of water elevation, current, and waves, if applicable, must be supplied to the PTM. The reader is referred to MacDonald et al. (2006) for the theoretical formulation and numerical implementation aspects of the PTM. An overview of features and capabilities of the PTM is presented in Davies et al. (2005). Demirbilek et al. (2005a) describe the PTM graphical interface. Demirbilek et al. (2005b) provide a tutorial with examples of the application of the model.

A Lagrangian modeling framework is one that moves with the flow, whereas in an Eulerian modeling framework, the solution is obtained at fixed points in space. In a Lagrangian framework, the waterborne constituent is represented as a finite number of discrete particles that are tracked as they are transported by the flow. Each particle represents a specified mass of the constituent (e.g., sediment particle) and has the same properties as the constituent, such as the settling speed and density. Both modeling frameworks are used in coastal engineering, and each has its advantages and disadvantages, depending on application. Eulerian models are useful for

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applications in which one is interested in the behavior of some material at a particular location (e.g., development of a scour hole). However, they must be solved for the entire domain, and model results are sensitive to grid and time resolution. Lagrangian models are useful for applications in which one is interested in the dynamics of a particular material or entity as it moves through a pre-defined domain (e.g., fate of sediment in transport). These models are computationally efficient because only the particles released are considered in the calculations. Lagrangian models simulate diffusion using a random walk method, and there is no numerical diffusion in a Lagrangian scheme. These models are appropriate for monitoring specific sediment particle sources without tracking other sediments in the domain.

The PTM combines particle transport computations using both Lagrangian and Eulerian methods, depending on an Eulerian hydrodynamic model such as CMS-Flow for current velocities. The SMS provides visualization tools for assessment of dredging practices and proposed dredging operations. Zundel et al. (1998) and Zundel (2007) describe the SMS and its features. The PTM is flexible, such that the complexity of particle behavior is user-defined and can range from highly resolved and intricate, where each simulated particle is subjected to the governing forces and kinematics as a single sediment particle, to a more integrated approach, in which particles are subjected to spatially averaged forces and react more like the total mass of sediment in the water column (MacDonald et al. 2006). Hydrodynamic input and output (I/O) of the PTM are stored in eXtensible Model Data Format (XMDF) binary data files (Jones et al. 2004). The inputs are water surface elevation and current calculated with a circulation model. Wave inputs to the PTM are wave field files from the CMS-Wave (Lin et al. 2006) model. Version 2.0 of the PTM expands capabilities from Version 1.0 to link directly to the CMS-Flow (Militello et al. 2004; Buttolph et al. 2006).

The PTM driven by the CMS is described here. This CHETN includes two examples of the coupled CMS-PTM, including the conversion process specific to the CMS and running the PTM within SMS10. Example 1 demonstrates an application of the PTM using a CMS simulation at Shinnecock Inlet, New York, with tides and waves specified at the model offshore boundary. Example 2 is another CMS field application for Poplar Island, Maryland, in Chesapeake Bay, where the usage of steps listed in Example 1 is demonstrated for the needs of an ongoing Corps of Engineers District project. Example 2 also illustrates the calculation of residence time with the coupled CMS-PTM system. This CHETN and files for the examples may be downloaded from http://chl.erdc.usace.army.mil/chetn and at http://xmswiki.com/.

COASTAL MODELING SYSTEM (CMS): The CMS applies the Eulerian approach and consists of numerical models integrated within the SMS10 user interface to dynamically simulate waves, currents, water level, sediment transport, and morphology change in the coastal zone. Emphasis is on sediment exchange between coastal inlets, navigation channels, and adjacent beaches and estuaries. The CMS was designed to assist in solving engineering problems at coastal inlets, such as navigation channel infilling, natural sand bypassing, consequences of mining ebb or flood tidal shoals, and changes in hydrodynamics and sediment transport in response to modifications to jetties or other coastal structures. The CMS contains coupled CMS-Flow and CMS-Wave models, which can also interact dynamically in driving sediment transport and morphology change. This CHETN illustrates the application of CMS hydrodynamic output (waves and current) within the PTM.

CMS-Flow: CMS-Flow is a two-dimensional (2D) or three-dimensional (3D) finite-difference flow model that employs a finite-volume, Eulerian approach to solve the depth-integrated continuity and shallow-water momentum equations of water motion (Militello et al. 2004; Buttolph et al. 2006). Wave forcing is included through coupling with CMS-Wave, which also provides wave radiation stresses. If required, the calculated current and morphology change can be input to the wave model to transform waves propagating on it. Coupling of the 2D version of the CMS with the PTM is discussed here.

Physical processes presently calculated by CMS-Flow are flow, water surface elevation, sediment transport, and morphology change forced by time- and space-varying water surface elevation (e.g., from tides or seiching), wind-speed dependent (time-varying) wind-drag, river discharge, and time- and space-varying wave-stress. Additional capabilities include flooding and drying, variably spaced bottom-friction coefficient, representation of non-erodible bottom (e.g., reef), efficient grid storage in memory, and hot-start options. It is also possible to independently turn on or off the advective terms, mixing terms, and wall friction for sensitivity analysis. CMS-Flow operates in SI (metric) units.

Three input files are required to conduct a CMS-Flow simulation (Table 1). These files are generated by the SMS10 when a CMS project is saved. The variable "proj" is a prefix given by users. The first input file is a text (ASCII) control file (proj.cmcards) that includes model input parameters and names of the input/output files. The second input file (proj_mp.h5) stores user-specified model computational forcing parameters and boundary conditions in XMDF binary file format. The third input file is a XMDF binary file (proj_grd.h5) for the geometry or grid data. The output file is a XMDF binary file (proj_sol.h5) for global solution calculations with water surface elevation and current velocity. The binary global solution file may contain multiple data sets within the XMDF data structure hierarchy, and the presence of these subsets is defined by input parameters in the control file. The CMS-Flow field prescribed as input to the PTM is spatially and temporally interpolated to resolve particle movement at finer scale than the input flow mesh. In typical applications, the input flow field will be 2D (depth-averaged). Support for 3D flow fields will be available in future versions of the PTM.

Table 1
CMS-Flow files.

File Name	Type	Description
proj.cmcards	Input – required	Control file for input model parameters and file pointer information
proj_mp.h5	Input – required	Model forcing parameters and boundary conditions
proj_grid.h5	Input – required	Elevation value at each node (i.e., grid geometry)
proj_sol.h5	Output – always	Global solution output calculation of water surface elevation and current velocity

A CMS-Flow simulation executed without sediment transport will generate two data subsets within the solution file, a scalar data set representing water surface elevation (*_elev), and a vector data set representing current velocity (*_vel), where "*" is used hereafter for generic file identifiers. Invoking sediment transport activates additional solution data subsets such as scalar bed morphology (morph), vector sediment transport (transAVG, transSUS, and transBED), and scalar sediment concentration (SedConcentration). Similarly, the binary XMDF grid file (*proj*_grd.h5) contains three data sets: distribution and crest depths of non-erodible cells (Hardbottom), distribution and value of Manning's friction coefficient (ManningsN), and cell depths (Depth). Figures 1 and 2 are examples of the SMS10 *Project Explorer* (also known as *Data Tree*) for typical CMS-Flow solutions with only hydrodynamics and the representative subsets.

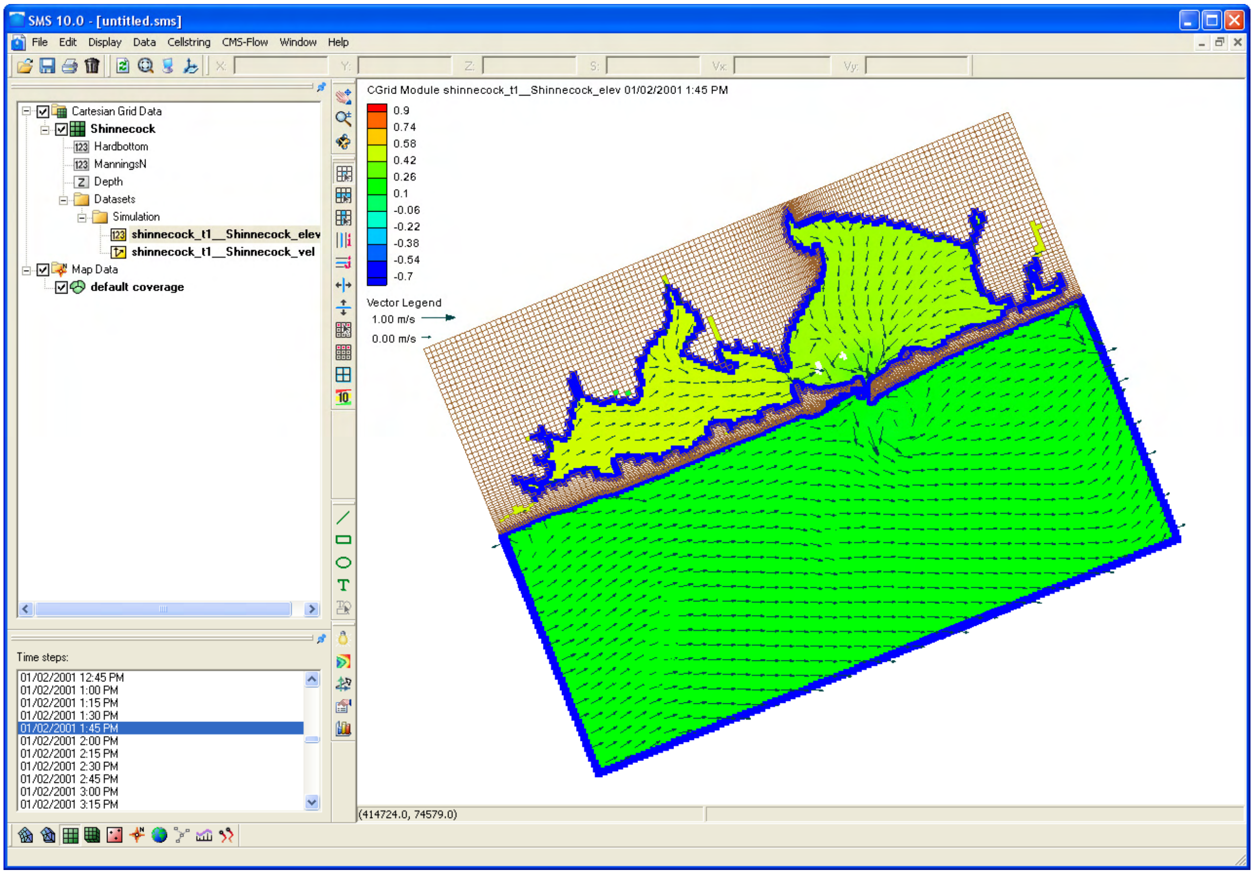


Figure 1. Example 1, Shinnecock Inlet, CMS-Flow simulation loaded into the SMS10.

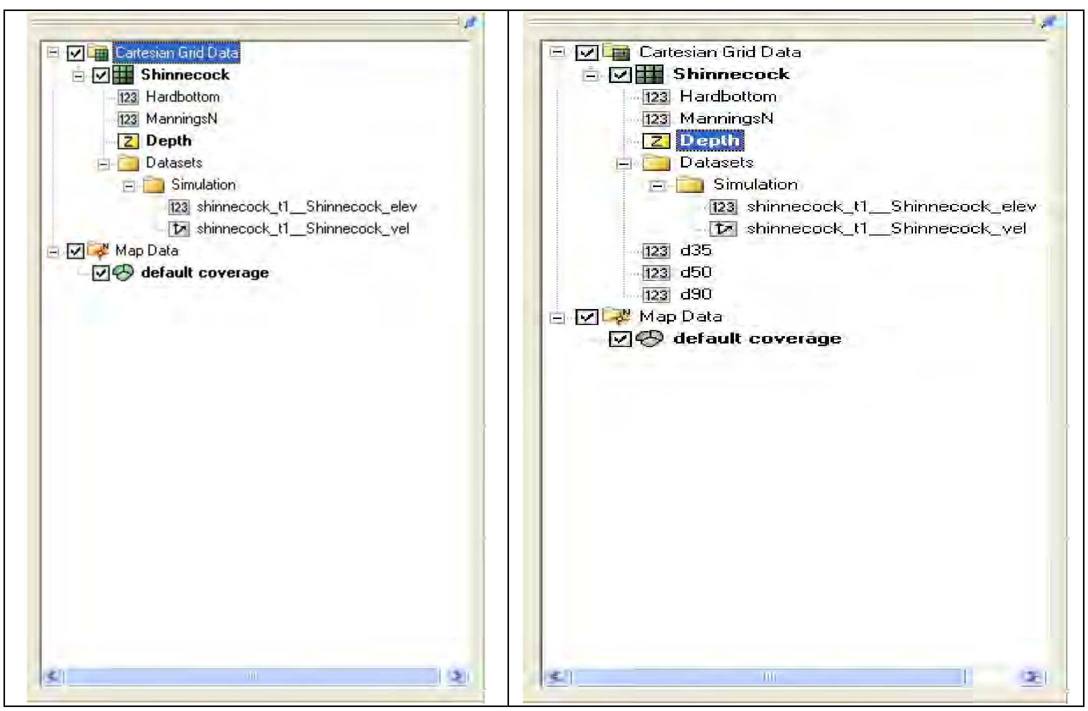


Figure 2. *Project Explorer* after opening project (left) and after creation of native bed sediment data sets (right).

CMS-Wave: CMS-Wave is a 2D wave spectral transformation model (Mase 2001; Mase et al. 2005; Lin et al. 2006; Demirbilek et al. 2007) implemented in the CMS through the SMS10. It is a phase-averaged model, which means it averages changes in the wave phase in calculating wave and other nearshore processes. CMS-Wave contains approximations for wave diffraction, reflection, and wave-current interaction and, therefore, is appropriate for conducting wave simulations at coastal inlets. It employs a forward-marching, finite-difference, steady-state (time-independent) Eulerian method to solve the wave action conservation equation. The model operates on a coastal half-plane so primary waves can propagate only from the seaward boundary toward shore. If the seaward reflection option is activated, CMS-Wave performs backward marching for seaward reflection after the forwarding-marching calculation is completed.

Four input files and one output file are required to perform a CMS-Wave simulation (Table 2). They are the simulation file (*.sim), the model parameters file (*.std), the depths file (*.dep), and the input directional spectra file (*.eng). Optional input files include a current field file (*.cur), a water level field file (*.eta), a friction coefficient field (friction.dat), a forward reflection coefficient field (forward.dat), and a backward reflection coefficient field (backward.dat). When executing CMS-Wave, users can pass the simulation file name to CMS-Wave as a command line argument or the program will prompt users for this file.

Table 2
CMS-Wave files.

File Name	Type	Description
proj.sim	Input – required	File names for input/output of a simulation
proj.std	Input – required	Model parameters and output options
proj.dep	Input – required	Elevation value at each node
proj.eng	Input – required	Input energy spectra – this includes one spectra for each open boundary for each wave case; wave spectra may be repeated
proj.cur	Input – optional	Value of current at each node (components parallel to x and y axes)
proj.eta	Input – optional	Water level field
friction.dat	Input – optional	Bottom friction coefficient field
forward.dat	Input – optional	Forward reflection coefficient field
backward.dat	Input – optional	Backward reflection coefficient field
proj.wav	Output – always	Wave height, period, and direction for each cell
proj.obs	Output – optional	Transformed energy spectra at selected cells
proj.brk	Output – optional	Breaking flag or energy dissipated at each cell
proj.rad	Output – optional	Radiation stress gradients (parallel to x and y axes) at each cell
proj.nst	Output – optional	Wave spectra for nested grids
selhts.out	Output – optional	Wave parameters at selected output cells
setup.wav	Output – optional	Wave setup and maximum water level field

Depending on which options are selected in the (*.std) file, CMS-Wave may generate one to seven output files. A wave field conditions file (*.wav) is always generated. Optional output files are calculated spectra (*.obs) and wave parameters (selhts.out) at selected cells, wave breaking indices (*.brk), wave radiation stress gradients (*.rad), wave setup and maximum water level field (setup.wav), and wave spectra for nested grids (*.nst). Table 2 presents a list of the type and

use of all I/O files, where "proj" is a prefix given by users for the project name. The simulation file (*.sim) stores the coordinates of origin and orientation of the computational grid, and a list of names of all files used in the simulation. All input and output files, required and optional, are listed in Table 2 with a short description of file purpose.

EXAMPLE 1: SHINNECOCK INLET

This section explains the steps for using I/O files from a CMS simulation for input to the PTM. The example is a CMS simulation for Shinnecock Inlet, with tide and incident waves specified at the model offshore boundary. For clarity, the SMS menu and PTM interface-specific functions are henceforth denoted in italic letters.

Shinnecock Inlet (Figure 3) is the easternmost federally maintained inlet located on the south shore of Long Island, NY. The U.S. Army Engineer District, New York, has conducted numerous studies in support of operations and maintenance at Shinnecock Inlet as well as for other inlets along the Fire Island to Montauk Point littoral cell. Several of these studies (Williams et al. 1998; Morang 1999; Pratt and Stauble 2001; Militello and Kraus 2001a) were in partnership with the CIRP, and several others (Militello and Hughes 2000; Militello et al. 2000; Militello and Kraus 2001a, 2001b; Militello et al. 2001; Buonaiuto and Militello 2004; Buonaiuto and Bokuniewicz 2008) employed the CMS (or its predecessor) to examine flow patterns, sediment transport, and morphology change at Shinnecock Inlet. Figure 3 illustrates the location of Shinnecock Inlet and Shinnecock Bay with respect to other inlets and bays along the south shore of Long Island. The landmass of Long Island is oriented about 28 deg north of east-west.

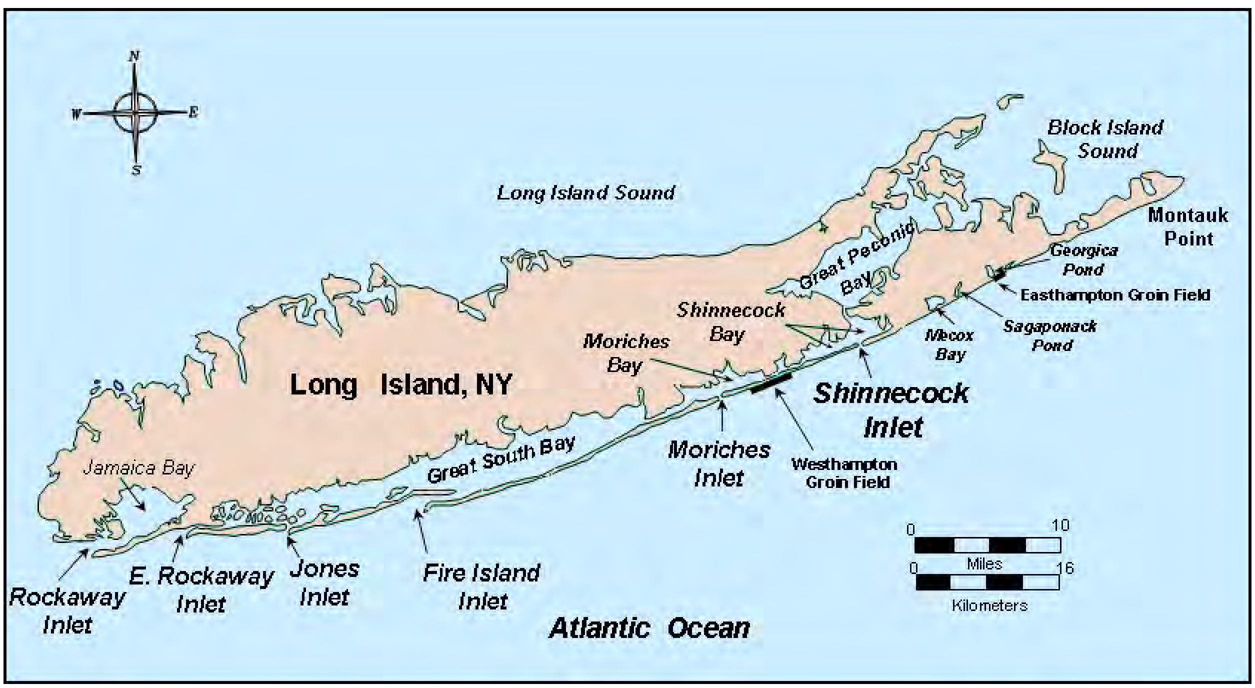


Figure 3. Location of Shinnecock Inlet, Long Island.

For this example, circulation was calculated within the CMS for Shinnecock Inlet by forcing the offshore boundary with a water surface elevation time series from a regional circulation model. Tides in the vicinity of Shinnecock Inlet are semi-diurnal and have a mean amplitude of 0.5 m (1-m range). Both the advective terms and the mixing terms of the momentum equation were calculated. Manning's number for bottom roughness was selected as 0.025 for the entire domain. The depth to begin drying cells was set to 0.05 m. Finally, the hydrodynamic time-step was 1 sec for all simulations.

Waves were modeled within the CMS by coupling CMS-Wave with CMS-Flow through the SMS10 steering interface with two-way feedback between waves and currents. In all cases, waves were held constant for the length of the simulation. Two variations in the constant wave forcing were simulated (Table 3).

Table 3
Wave designations for Shinnecock Inlet example CMS simulations.

Designation	Significant Wave Height, m	Spectral Peak Period, sec	Mean Wave Angle, deg
Typical	1.5	11	20
Storm	3.5	14	75

After launching SMS10, the user selects the coordinate system to be used with the *Current Coordinates …* command in the *Edit* menu. For the case described below (and unless stated otherwise), the default units should always be meters for the two horizontal and vertical coordinates.

Step 1. Loading CMS Simulation Data: For a PTM simulation, I/O files from CMS-Flow or, if applicable, I/O files from both CMS-Flow and CMS-Wave may be loaded into the SMS10 or, as an alternative, may be accessed externally from any directory by loading the required files into the *Files* tab of the PTM *Model Control* window. For demonstration purposes, the CMS-Flow and CMS-Wave files will be loaded into the SMS10 for this CHETN example. The data in a CMS simulation are accessed through a project file (*.sms), which references all the parameter files, grid files, surveys, map files, image files, and metadata pertinent to a project. This includes the CMS-Flow control file (*.cmcards), the model parameter file (*_mp.h5), the grid file (*_grd.h5), and the hydrodynamic solution file (*_sol.h5), as well as the entire CMS-Wave simulation (*.sim). Use the *Open* command in the *File* menu to select the appropriate file (file name: Shinnecock.sms) to load the project files listed in Table 2. If there is no SMS10 project file (*.sms), the user can open the CMS-Flow cards file (*.cmcards) to load the CMS-Flow simulation into SMS10. When the flow files are opened, SMS10 reads the grids, and related solution data are displayed as shown in Figure 1. The CMS-Flow grid is represented in the *Project Explorer* under the name Shinnecock. Below this entry are the data sets for Hardbottom, ManningsN, and Depth (solution files), which contain the water surface elevation and current velocity data sets.

The CMS-Wave simulation file (*.sim) can also be loaded if applicable, and users may wish to do so. However, if users want to avoid cluttering of the listed files in the project explorer, it is not necessary to load wave files at this step because they can be linked to CMS-Wave files. The wave solution files can be accessed directly by the PTM; they do not need to be opened in the interface. (See Step 9 for instructions for accessing wave files in Example 1.)

SMS10 supports the display of time units in several formats. For this example, the starting time of the CMS-Flow run has been set as the reference date. The *Model Control* command in the

CMS-Flow menu shows the *Start date* of 01/01/2001 at 12:00 a.m., or midnight. Use the *Time Settings* command in the *Edit* menu to set this date as zero time. There are several time setting formats available in SMS10 that users can select. The user-selected format must be used in all steps where applicable.

With the required CMS hydrodynamic files loaded in the SMS10, the project explorer appears as shown in the left side of Figure 2. Users can refer to Demirbilek et al. (2005a, 2005b), Davies et al. (2005), and MacDonald et al. (2006) for information about specification of particle sources, generation of boundary conditions for the PTM, and creation of sediment particle traps required to calculate the residence times. Steps and guidance for these PTM inputs have been presented in the previously published references. Sediment specification for the PTM is outlined in Step 2, and the required native sediment inputs (bed sediments) are listed on the right side of Figure 2. The generation of PTM boundary conditions is discussed in Step 3.

Step 2. Generating Sediment Data: The PTM requires native (bed sediment) data, defined by the labels d35, d50, and d90 for each cell in the CMS-flow grid. The PTM reads these values as data sets from an XMDF (binary) input file. If spatial surveys of bed sediments are available, they may be interpolated to the grid (Buttolph et al. 2006; Zundel 2007). If this is not the case, a constant sediment type can be defined using the *Data Calculator* tool, found in the *Data* menu. To do this for this example, first ensure that the CMS-Flow grid is highlighted. Open the *Data Calculator* and create a d90 data set by entering the value 0.5 (mm) in the *Data Expression* input, and the name d90 in the *Name of result*. Press the *Calculate Data Expression* button. Repeat this procedure to create d50 (0.25 mm) and d35 (0.15 mm). Sediment sizes must be specified in millimeters. Press the *Done* button after all three have been entered. The Project Explorer will update to represent these additions, as shown on the right side of Figure 2. To save these data sets to a file, select the three sediment data sets (d35, d50, and d90), right click, and select *Export Datasets….* This operation will invoke the *Export Data Set* dialog. Change the file type to *XMDF File*, select the option to save all time steps, and specify the file name to save (NativeSediments.h5). Click the *Save* button.

Step 3. Generating the Boundary Conditions: The PTM requires boundary types (open or closed) to be specified around the exterior of its computational boundaries. CMS-Flow only requires the specification of open boundaries, so part of this information may need to be generated using the SMS10. To check this, view the cell strings defined on the CMS-Flow grid by selecting the *Select Cellstring* tool (). The SMS10 displays a selection box for each boundary cell string in the model (Figure 4). In the example, boundary specification exists for all of the open and land boundaries. If this were not the case, the user would have to add specifications on the undefined boundaries by selecting the CMS-Flow grid and issuing the *Generate Along Boundary* command from the *Cellstring* menu. The SMS10 generates new cell strings around all boundaries, which all default to closed boundaries (Zundel 2007). Along the open boundaries, the newly created redundant cell strings must be deleted. Care should be taken to delete only the redundant boundary specification, which is identified as a land boundary. Do not delete the open boundary cell strings. To determine which string is redundant, the user can select one of the two cell strings and choose *Assign BC…* from the *CMS-Flow* menu. If the boundary condition type that appears is *Land*, this cell string should be deleted. If not, the other cell string at that location should be selected and deleted. Repeat this procedure for all duplicate cell strings.

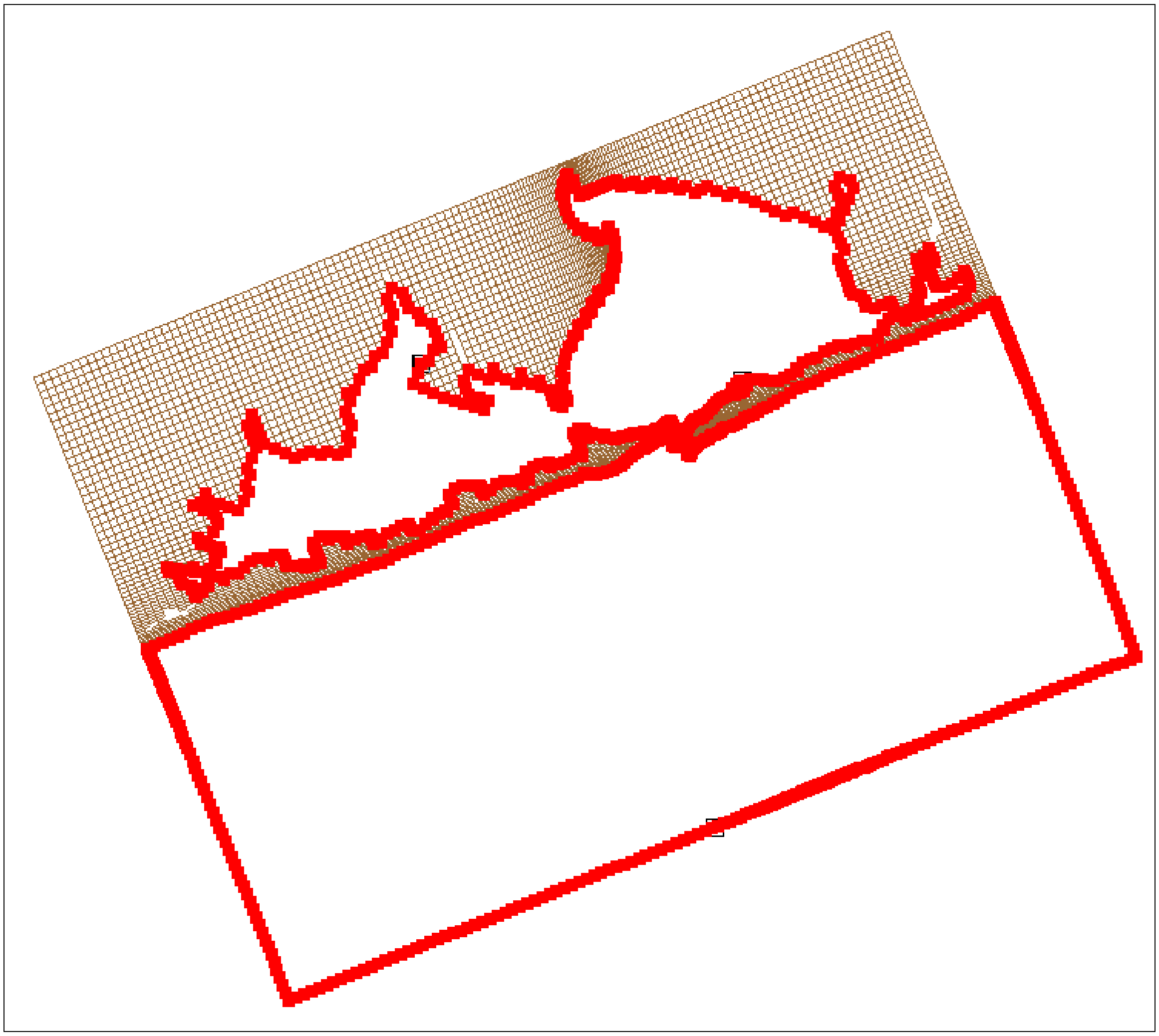
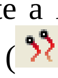


Figure 4. Existing Boundary *Cellstrings* (in red) for Example 1.

The hydrodynamic data, sediment data, and boundary conditions from the CMS and from the SMS are now complete and ready for the PTM application. These changes should now be saved. The project file is saved with *File* menu and *Save Project* command. This operation writes the PTM boundary conditions to the model parameters file.

Step 4. Creating PTM Model Control Data: To initiate a PTM simulation, switch to the PTM model interface by selecting the particle module icon (). Select *New Simulation* from the *PTM* menu. This creates a PTM simulation in the Project Explorer named *Part Set*. Select *Model Control* from the *PTM* menu to open the menus available in the *Model Control* interface.

Step 5. File Specifications: Switch to the *Files* page to begin entry of data (Figure 5).

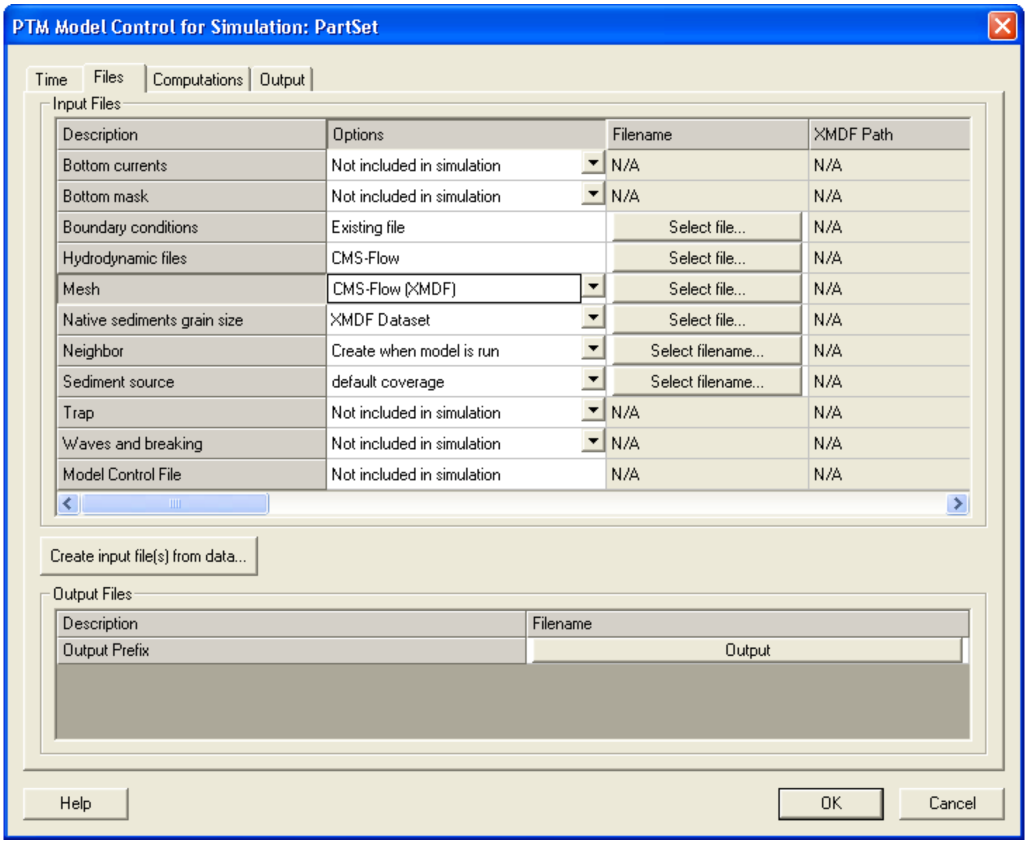


Figure 5. *Files* page in *Model Control* of the PTM prior to entry of data sets.

Step 6. Mesh Selection: Entry of information should begin with the *Mesh* (*Grid*) file type and name. In the *Options* column, select *CMS-Flow (XMDF)* and click on the *Select file…* button in the *Filename* column. This selection brings up a browser to choose a file. Select the shinnecock_t1_Shinnecock_grid.h5 file. Once a file is selected, a *Select paths…* button appears in the *XMDF Path* column. Click this button, which opens the *Select XMDF Path* window (Figure 6). For the mesh, the PTM extracts the grid definition and the depths, so paths to these two entities must be specified. Because the CMS-Flow data were provided in XMDF format, the *Model Control File* should not be specified.

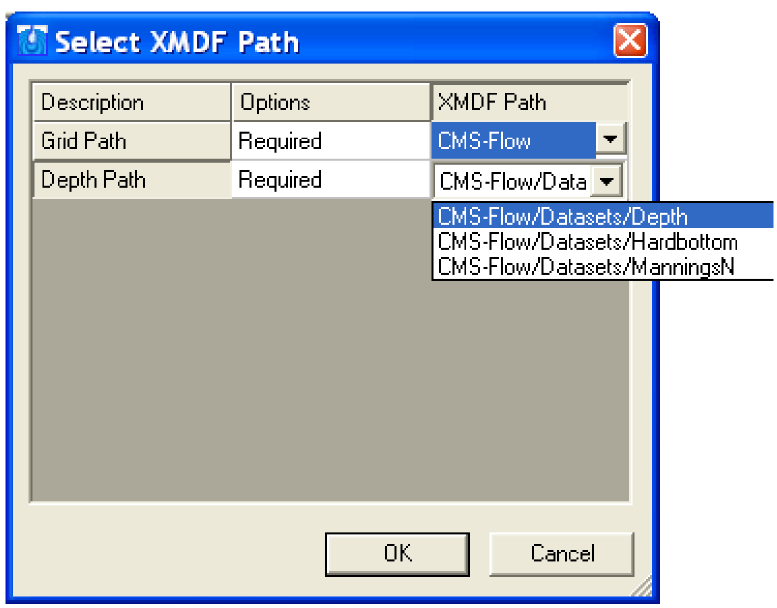


Figure 6. The window used to verify path names for CMS-Flow input files.

Step 7. Hydrodynamic Files Selection: Specify the *Hydrodynamic files* (shinnecok_t1_Shinnecock_sol.h5) by selecting the paths to the velocity and water surface elevation fields in the *Select XMDF Path* window. (They should be defaults.)

Step 8. Boundary Condition Selection: Specify the *Boundary conditions* to be used by the model parameters file (shinnecock_t1_Shinnecock_mp.h5).

Step 9. Waves and Breaking Selection: Because output for waves and breaking is in separate files (Table 2), both file types are required for a PTM simulation with waves (MacDonald et al. 2006). Set the *Waves and breaking* type to *CMS-Wave*. This enables an *Options* menu. Click this button, and a *Waves* window will open to facilitate entry of the wave data (Figure 7). Because the wave grid is opened in the SMS10 interface, the *Get Geometry from Grid* button can be pushed to load the grid origin coordinates. In this window, load the *.wav files by clicking on the *Load* **(***.wav**)** button, and select the two wave files associated with this project (#swsteer.wav). Click open. Repeat this process with the *Load* **(***.brk**)** button to load the two wave breaking files. Now, check that the files are loaded in the correct order; use the up and down arrows (↑/↓) to reorder the files, if required. If there are multiple files and all files are loaded at the same time, users will need to move these files to ensure they are in the correct order (the first *.wav and *.brk files followed by the second *.wav and *.brk files in this example). Click the OK button to finish specifying the wave data. Figure 7 shows the CMS Steering simulation (coupled run of CMS-Flow and CMS-Wave) for Example 1 with the wave condition files (1swsteer.wav and 2swsteer.wav, and corresponding *.brk files).

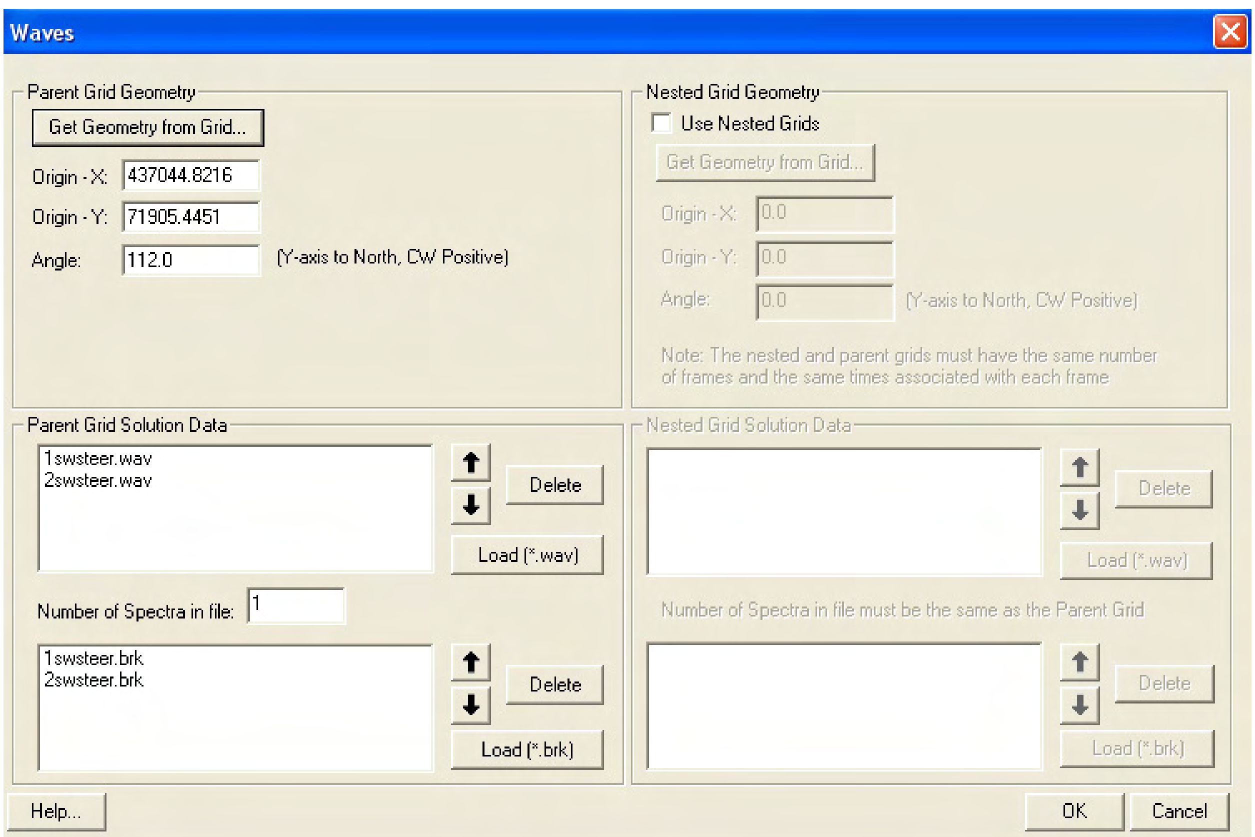


Figure 7. *Waves* page of the *Model Control* in the PTM interface.

Step 10. Sediment Source Selection: MacDonald et al. (2006) and Demirbilek et al. (2005a, 2005b) describe types of sediment sources that can be specified for input to the PTM and the procedure for creating PTM source files in SMS. For illustration in this example, a sediment source file is provided. The sources consist of three point mass rate sources, with one positioned inside the bay in the ebb tidal channel (d_{50} = 0.1 mm), another positioned inside the ebb shoal (d_{50} = 0.3 mm), and the third positioned west of the ebb shoal downdrift bypass bar (d_{50} = 0.3 mm). Also, one horizontal line source is positioned across the surf zone east of Shinnecock Inlet (d_{50} = 0.25 mm). Figure 8 shows the locations of the particle sources superimposed over the depth contours. In the *Files* page of the *Model Control* (Figure 5), the user sets the *Options* column to *Existing file*, clicks the *Select file…* button in the *Filename* column, and chooses the file line.source.

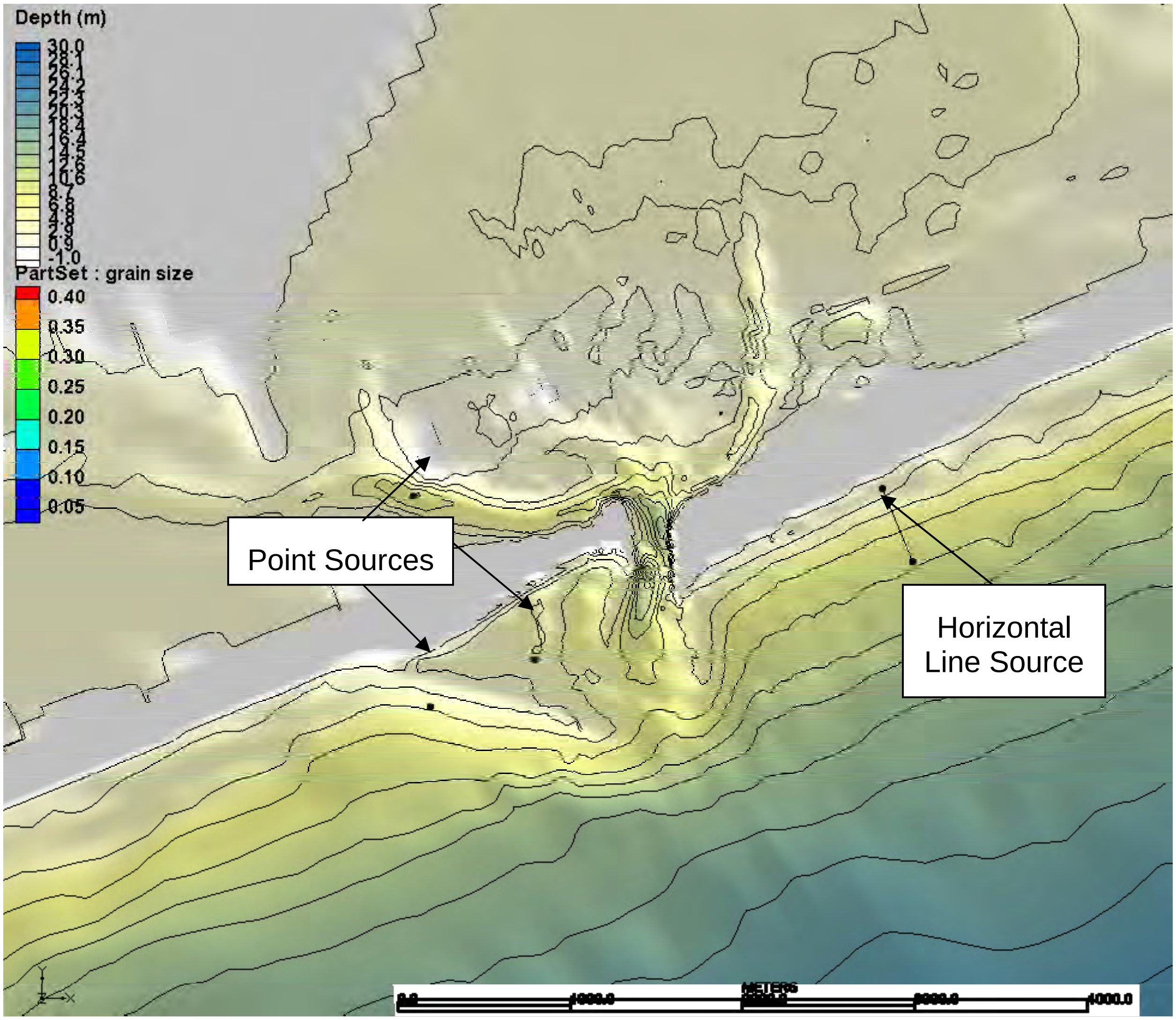


Figure 8. Locations of PTM sources within the CMS-Flow model domain.

Step 11. Neighbor Selection: The neighbors file is the PTM's geometry (grid file), and it is used by the model for calculations (MacDonald et al. 2006). The creation of the neighbor data file is performed only once for each hydrodynamic model grid. This information can be time-consuming to obtain for large grids; once computed, this additional information is written to a neighbors file (extension *.neighbors*). On subsequent simulations, the information is read from the neighbors file. If no neighbors file exists, the model will create one using the user-provided name for the neighbors file. The name of the neighbors file is specified by the user on the *Files* page in the *Model Control* menu (Figure 5).

Step 12. Native Sediments Selection: In the native sediments line, specify *XMDF Dataset* in the *Options* column. Next, click on the *Select file…* button in the *Filename* column and choose the NativeSediments.h5 file created earlier. With a file selected, a *Select paths…* button appears in the *XMDF Path* column as it did for the mesh above. Select the path for each of the three data sets created earlier (d35, d50, and d90). The completed *Files* page is shown as Figure 9.

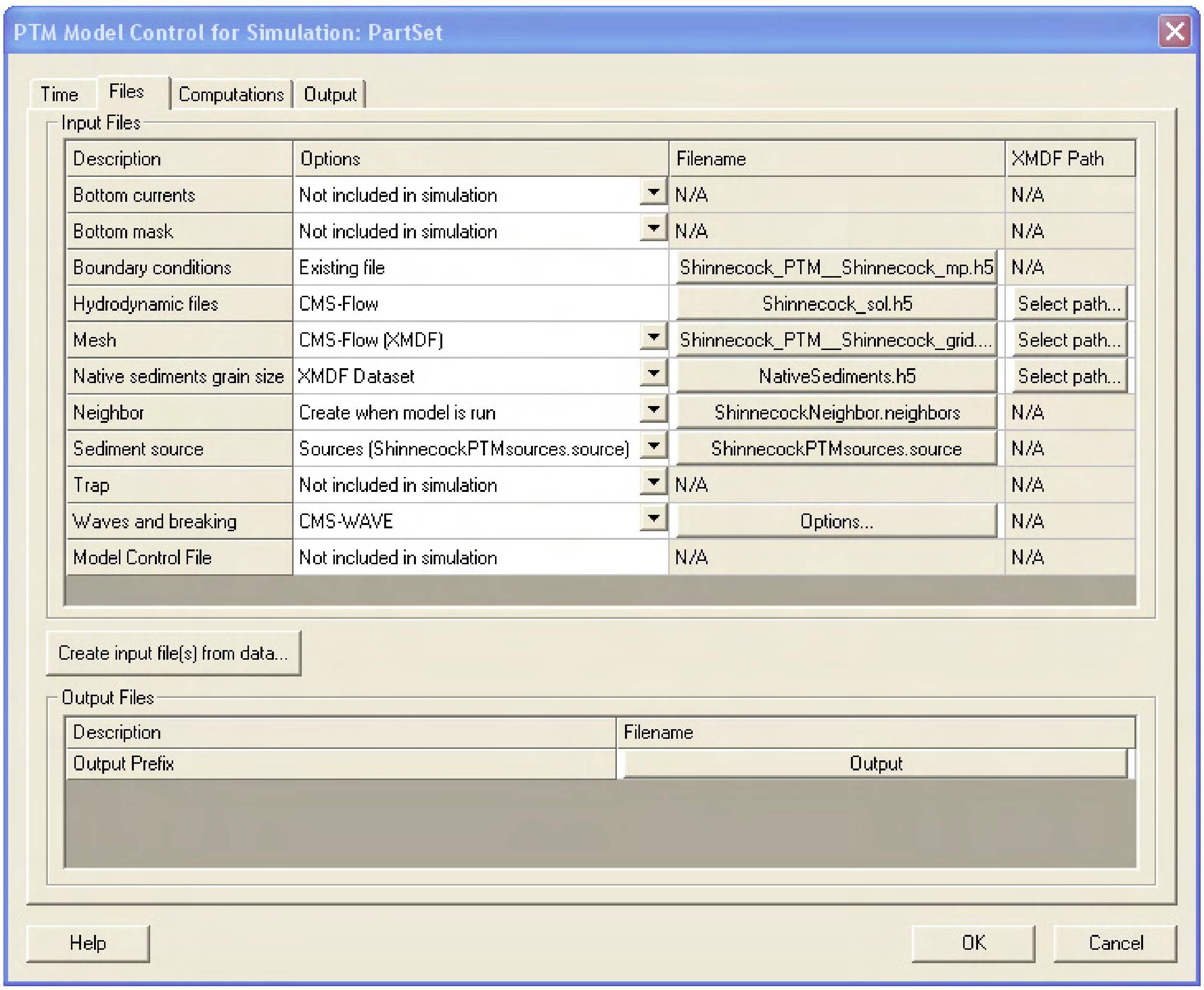


Figure 9. *Files* page of the *Model Control* after entry of data sets for a PTM simulation.

Step 13. Time and Computation Specifications: The other three pages of the interface should also be loaded with data for the simulations. Although the PTM interface pages in SMS10 are new, the content is similar to that described in Demirbilek et al. (2005b) and MacDonald et al. (2006). Examples of completed pages are shown as Figures 10–12.

Step 14. Output Options: The *Output* tab allows modification of which options are available in the other tabs, so users may want to specify these options first. For reading the solution into SMS10, the *ID* and *Elevation* output options are required and should be checked. The other options available are based on the task being performed. Typical options are displayed in Figure 10.

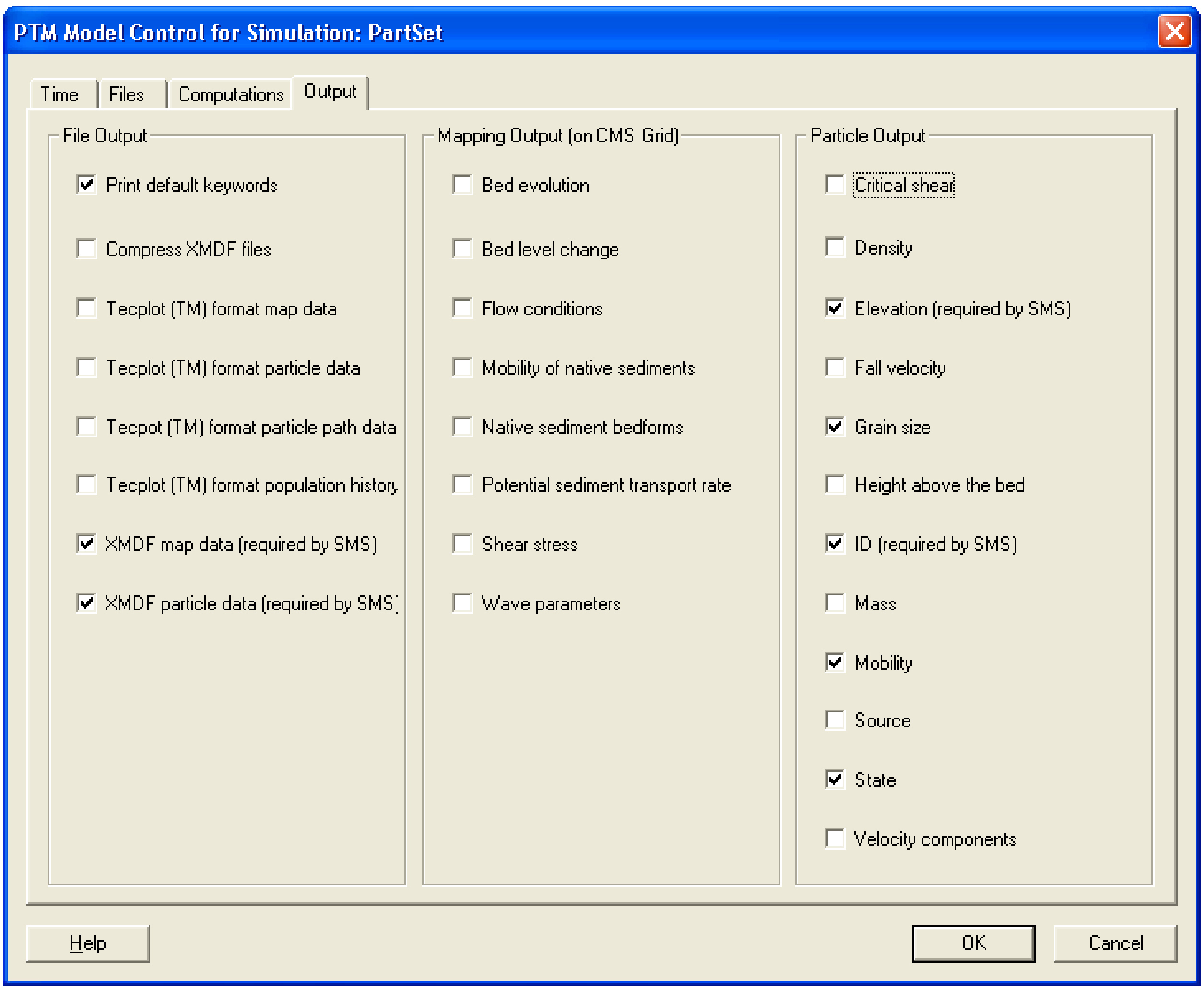


Figure 10. Completed settings for *Output* page in *Model Control* for Example 1.

Step 15. Time Options: The *Time* tab of the *Model Control* menu allows users to specify the duration of the PTM run and how it should interact with the hydrodynamic and wave data. For this Example 1, a short 2.5-day run illustrates the particle motion. The duration of the run or the ending time can be specified. Setting the *Stop date* to 01/03/2001 12:00:00 p.m. tells the PTM to simulate 2.5 days of particle activity. Next, set the Time Step to 10.0 sec. The other options should appear as shown in Figure 11.

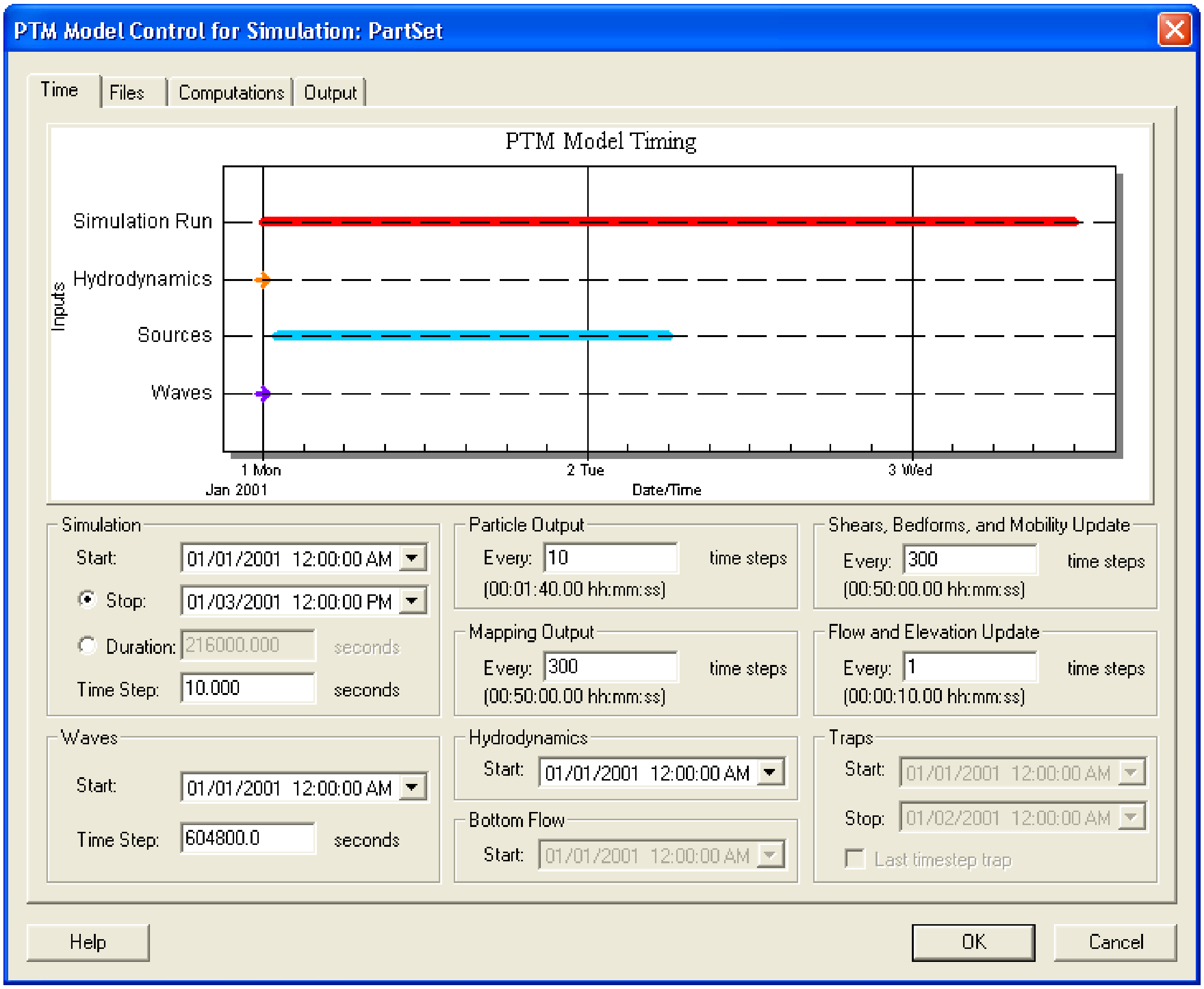


Figure 11. Completed *Time* page in *Model Control* for Example 1.

Step 16. Computation Options: The computation tab includes model settings. Set the controls to match Figure 12 for this example.

Step 17. Running the PTM: Press the *OK* button to close the PTM model interface window. Save the project file in the *File* menu. The PTM model can now be executed from the *PTM* menu. The CMS-Flow and CMS-Wave I/O files and results for Example 1 may be downloaded from the following websites: http://cirp.wes.army.mil/cirp/ and http://xmswiki.com/.

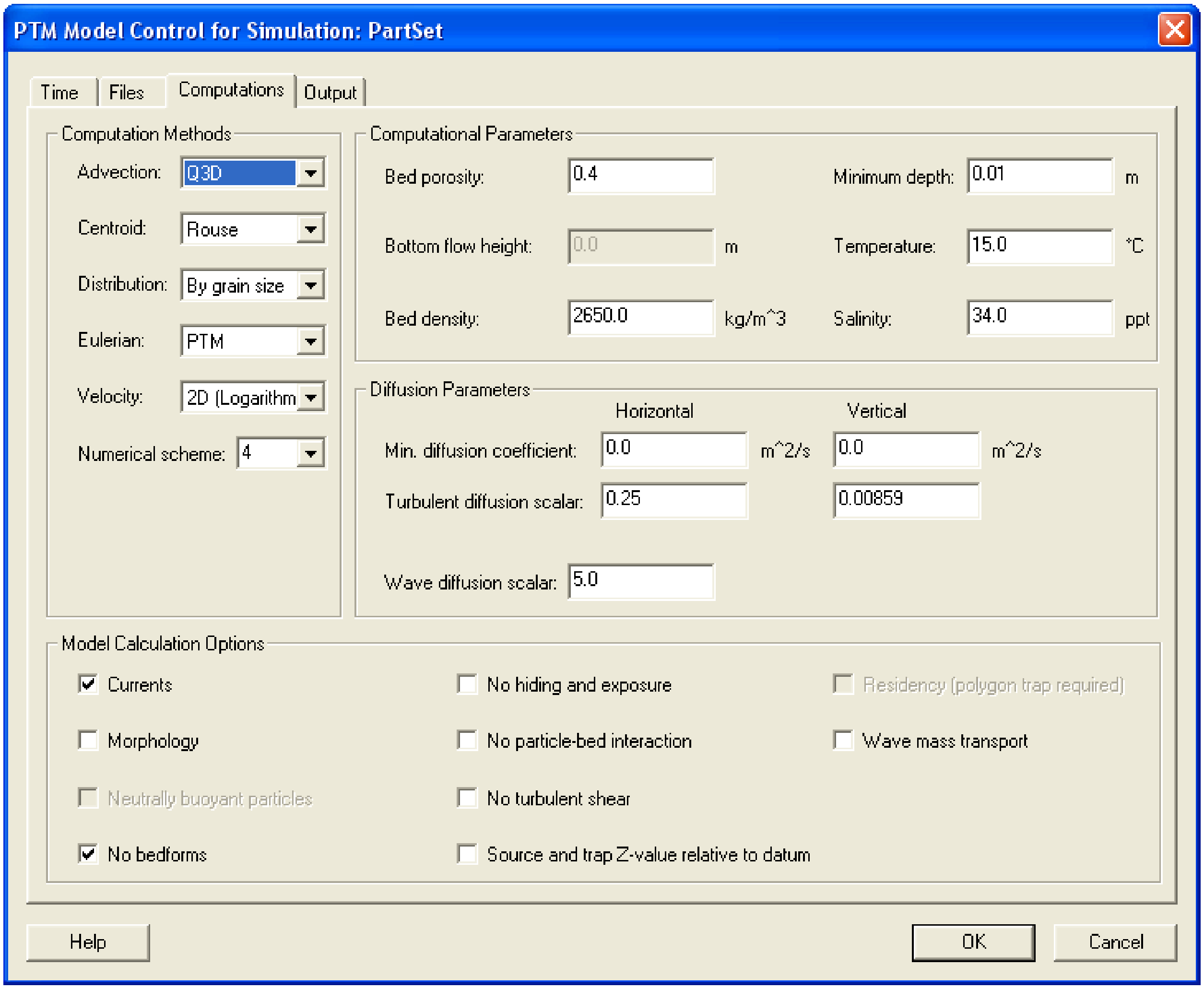


Figure 12. Completed *Computations* page in *Model Control* for Example 1.

Representative results from the Shinnecock Inlet example PTM simulation under typical waves are presented in Figures 13–15, and the results from the example PTM simulation under storm waves are presented in Figures 16–18. During the first ebb tide under typical waves (Figure 13), particles from all three point sources are transported toward the inlet channel, then offshore with the ebb current, while particles from the horizontal line source are transported east with the longshore current. Despite an offshore incident angle of 20 deg, relative to shore normal, the longshore current is eastbound because of local shoreline orientation. Although net transport along this coast is from east to west (Panuzio 1968; Kana 1995), this current pattern is representative of a typical summer condition. As one would expect, particles released within the surf zone, where the longshore current is at its maximum velocity, are transported at a greater rate than those released along the offshore portion of the horizontal line source.

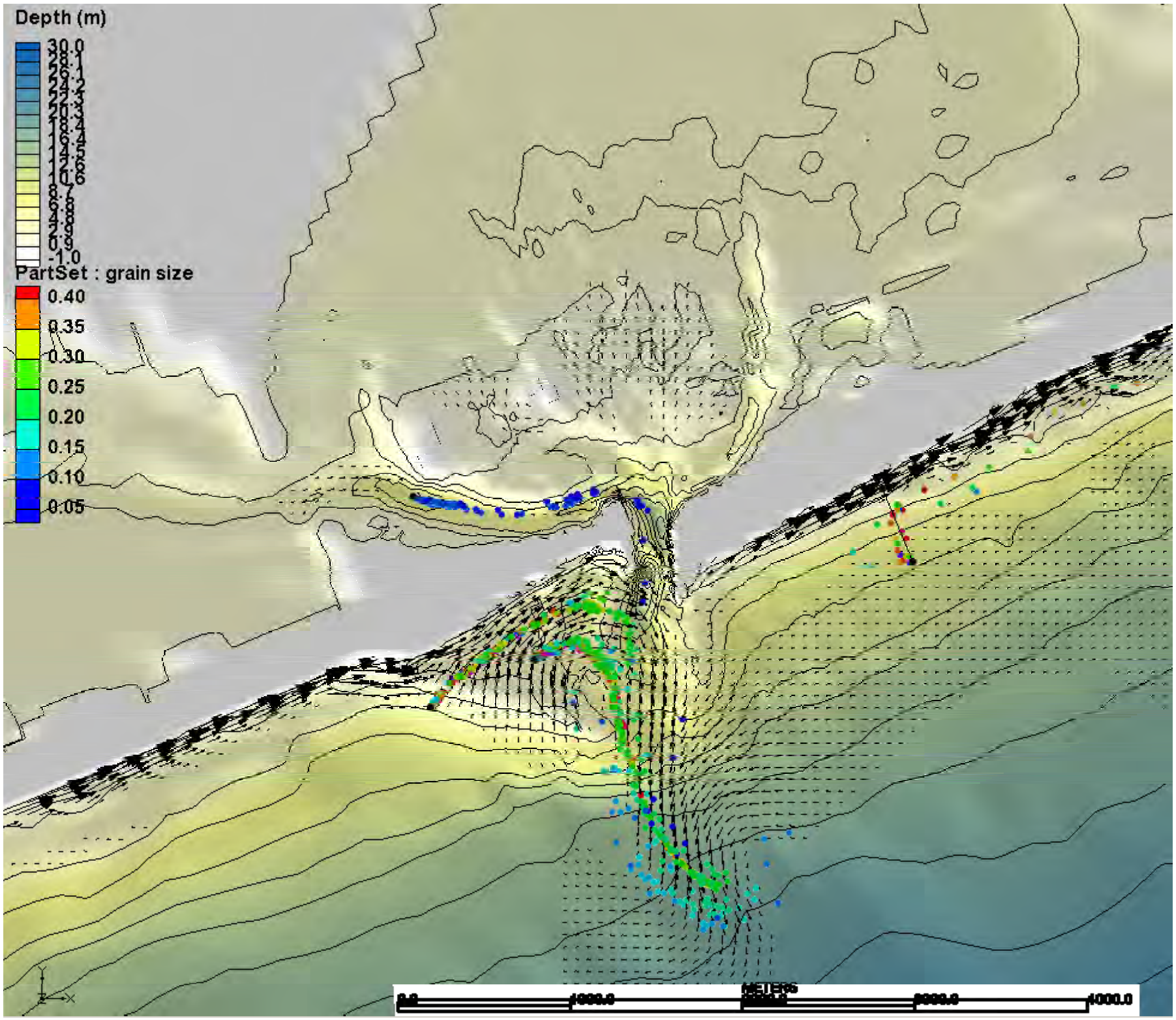


Figure 13. Distribution of particles after first ebb tide (5 hr after particle release for typical waves).

During the first flood tide under typical waves (Figure 14), particles from the two point sources near the ebb shoal are transported into Shinnecock Bay, up onto the flood shoal, and into the flood and ebb channels that bifurcate the flood shoal. Some particles released from the two sources during the previous ebb tide remain suspended seaward of the ebb shoal. Particles released inside the bay are transported along the western ebb channel, and sorting by grain size is observed. Smaller (blue) particles released from this source are transported farther west into Shinnecock Bay, while larger (green and red) particles remain in the channel as a result of reduced current as they travel farther into the bay. Particles released from the horizontal line source along the surf zone continue to be transported east with the longshore current, while outside of the surf zone some weak transport to the west occurs.

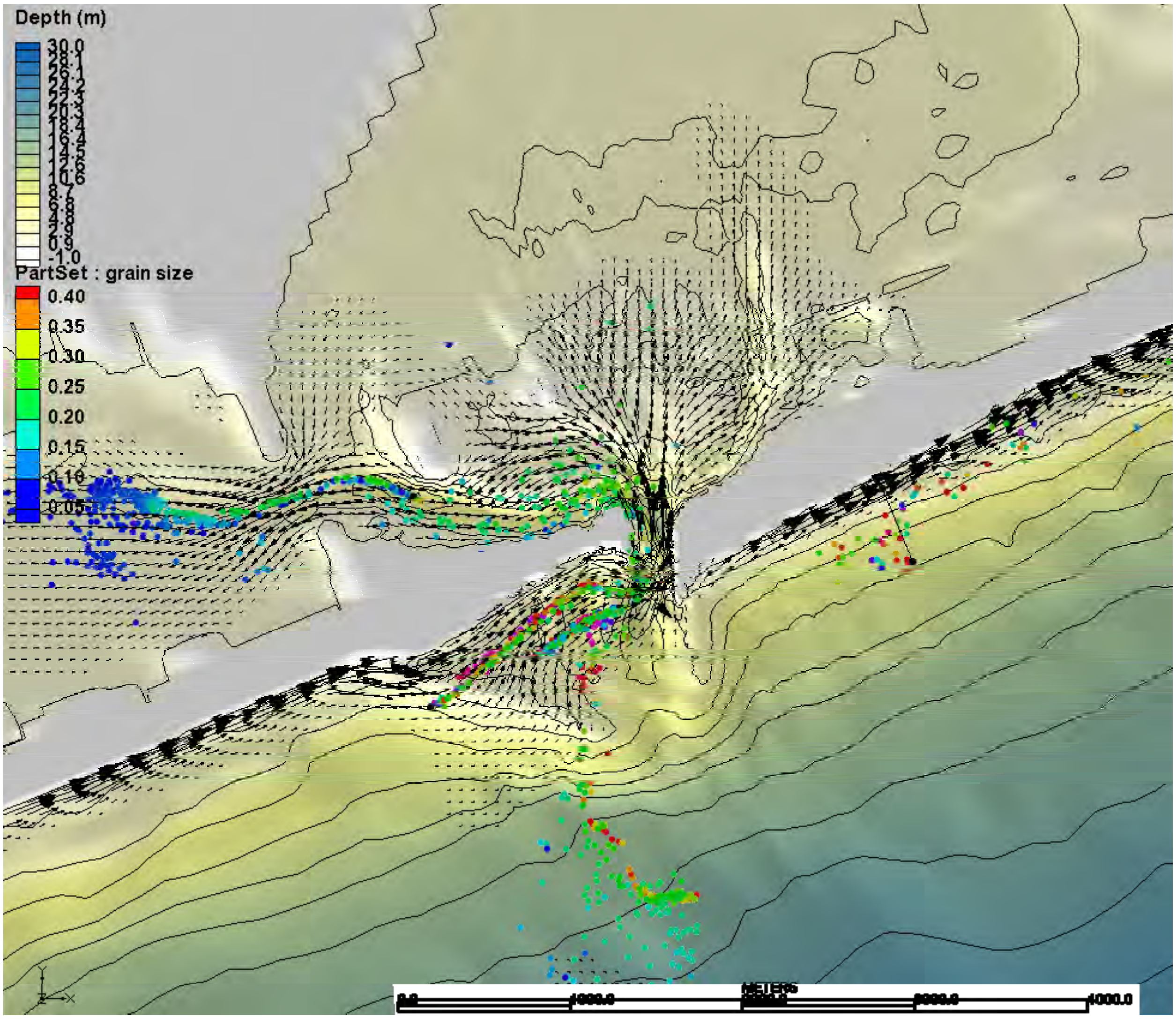


Figure 14. Distribution of particles after first flood tide (9.5 hr after particle release for typical waves).

Results at the end of the 2.5-day PTM simulation under typical waves are presented in Figure 15. This figure shows clear patterns of grain size sorting both within the bay and offshore. Of note are the crescent-shaped deposition of larger grain (red and green) particles, which mimics the morphology of the ebb shoal only farther offshore, and the finer grain (blue) particles that continue in suspension and are transported offshore. A crescent-shaped deposition pattern is created by the east to west migration of the eddy (visible in the current velocity vectors in Figure 15) associated with the ebb tidal jet. This pattern is consistent with the findings of Militello and Kraus (2001a, 2001b). Additional options for post-processing and visualization of results in the SMS are described in Demirbilek et al. (2005b), Zundel (2007), and at http://xmswiki.com/.

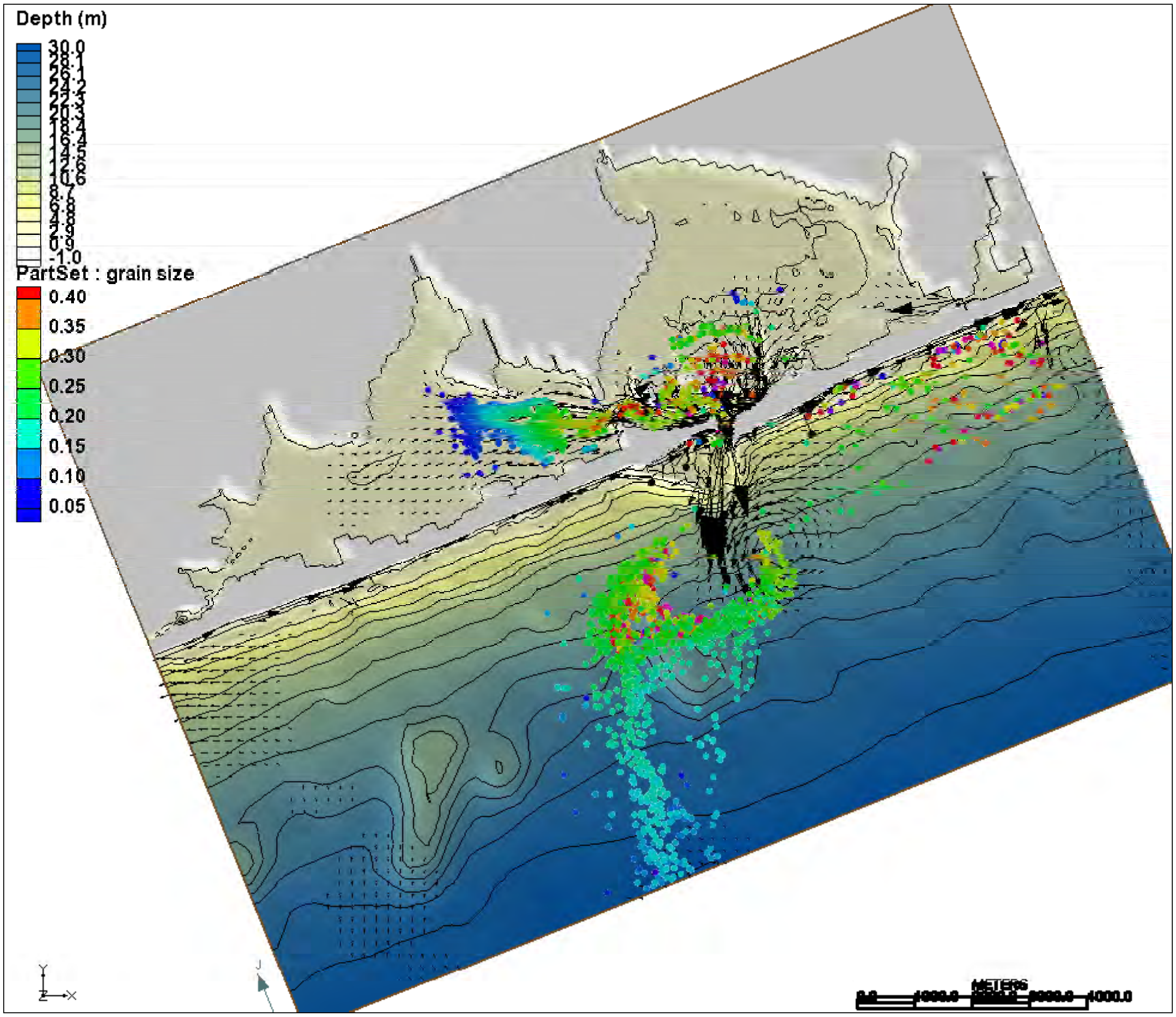


Figure 15. Distribution of particles 2.5 days after particle released for typical waves.

During the first simulated ebb tide under storm waves (Figure 16), particles released from the point source west of the ebb shoal attachment bar are transported west along the beach, while particles released east of the attachment bar are transported toward the inlet channel, indicating that the attachment bar functions as a nodal point. Particles released from the horizontal line source are transported west with the longshore current and converge in the channel with particles released from the bay source and the source east of the attachment bar. An offshore incident angle of 75 deg, relative to shore normal, is frequently encountered during extratropical storms, and the longshore current is westbound and representative of the net longshore transport direction.

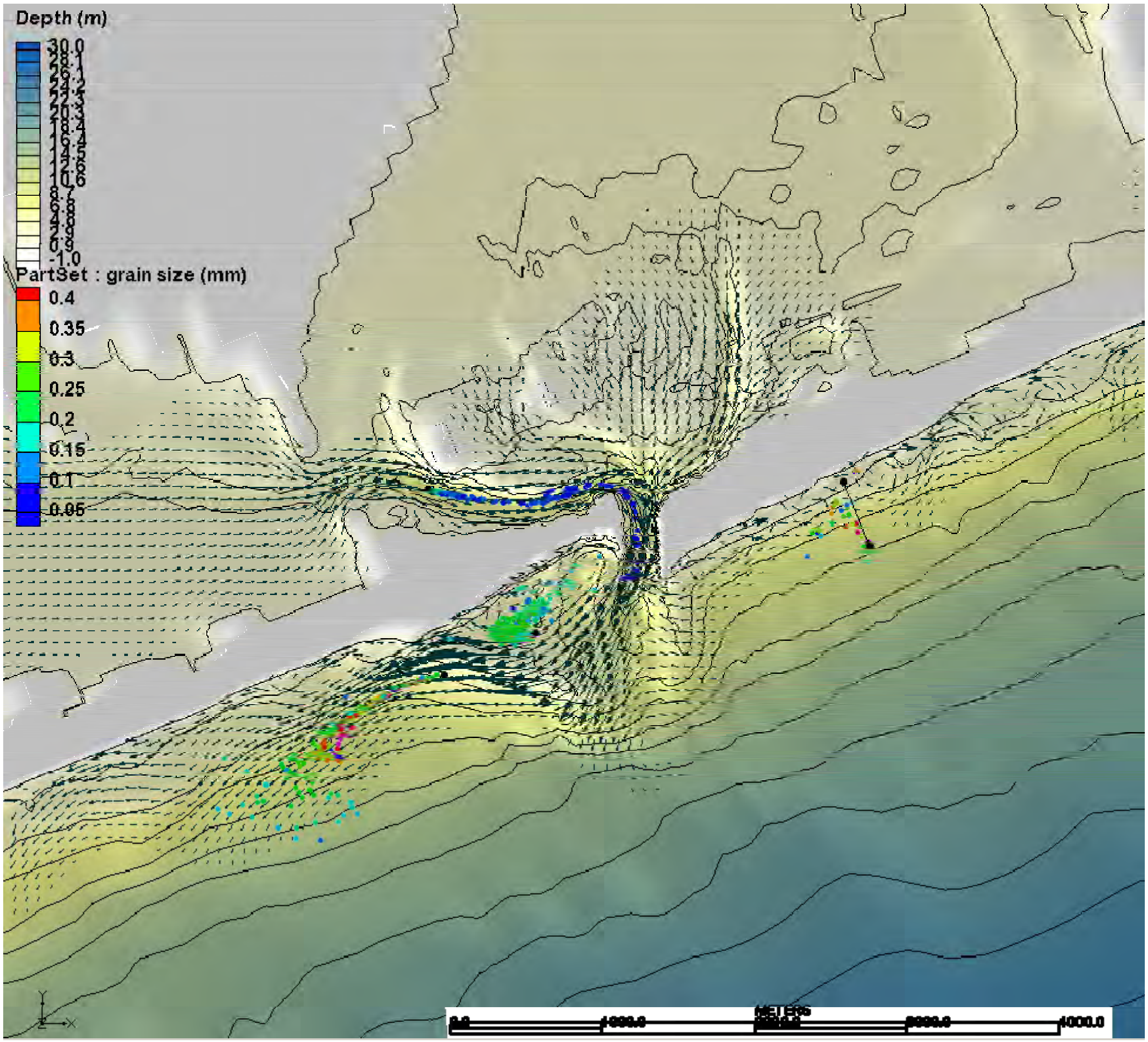


Figure 16. Distribution of particles after first ebb tide (5 hr after particle release for storm waves).

During the first flood tide under storm waves (Figure 17), particles from the point source west of the ebb shoal continue to be transported west along the beach, away from Shinnecock Inlet. Particles released from the three other sources continue to be transported toward the inlet and into the bay, primarily along the west ebb channel. No particles released from these sources remain offshore of the ebb shoal. Similar to the previous simulation, particles released inside the bay are transported along the western ebb channel, and sorting by grain size is observed.

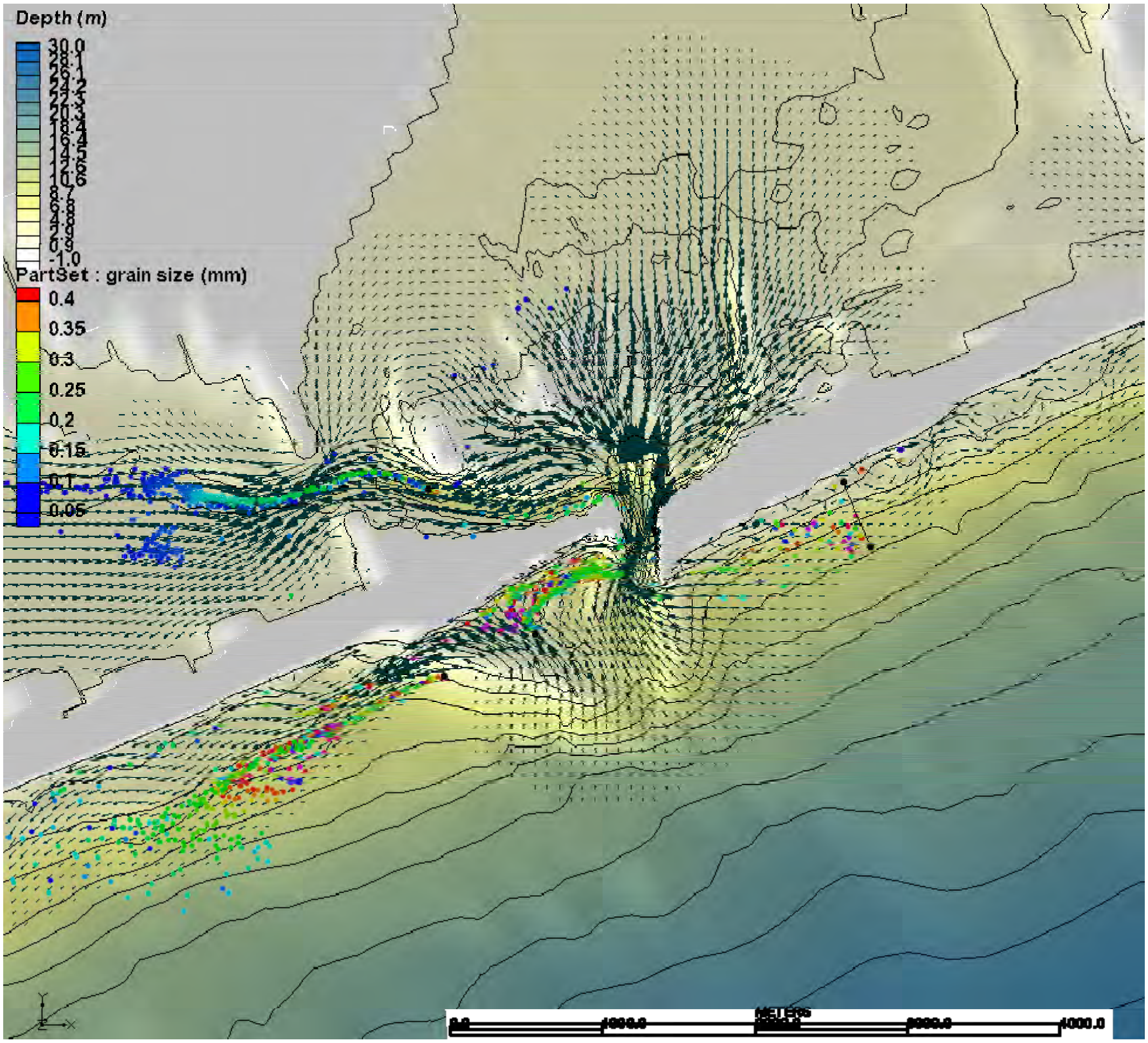


Figure 17. Distribution of particles after first flood tide (9.5 hr after particle release for storm waves).

Results at the end of the 2.5-day PTM simulation under storm waves are presented in Figure 18. This figure shows clear patterns of grain size sorting both within the bay and offshore of the downdrift surf zone. All particles that remain outside of the bay are transported west of Shinnecock inlet with the longshore current. A crescent-shaped deposition pattern visible in the typical simulation is not observed in this storm simulation, an indication that wave-induced longshore transport dominates transport resulting from tidal current during this simulated storm.

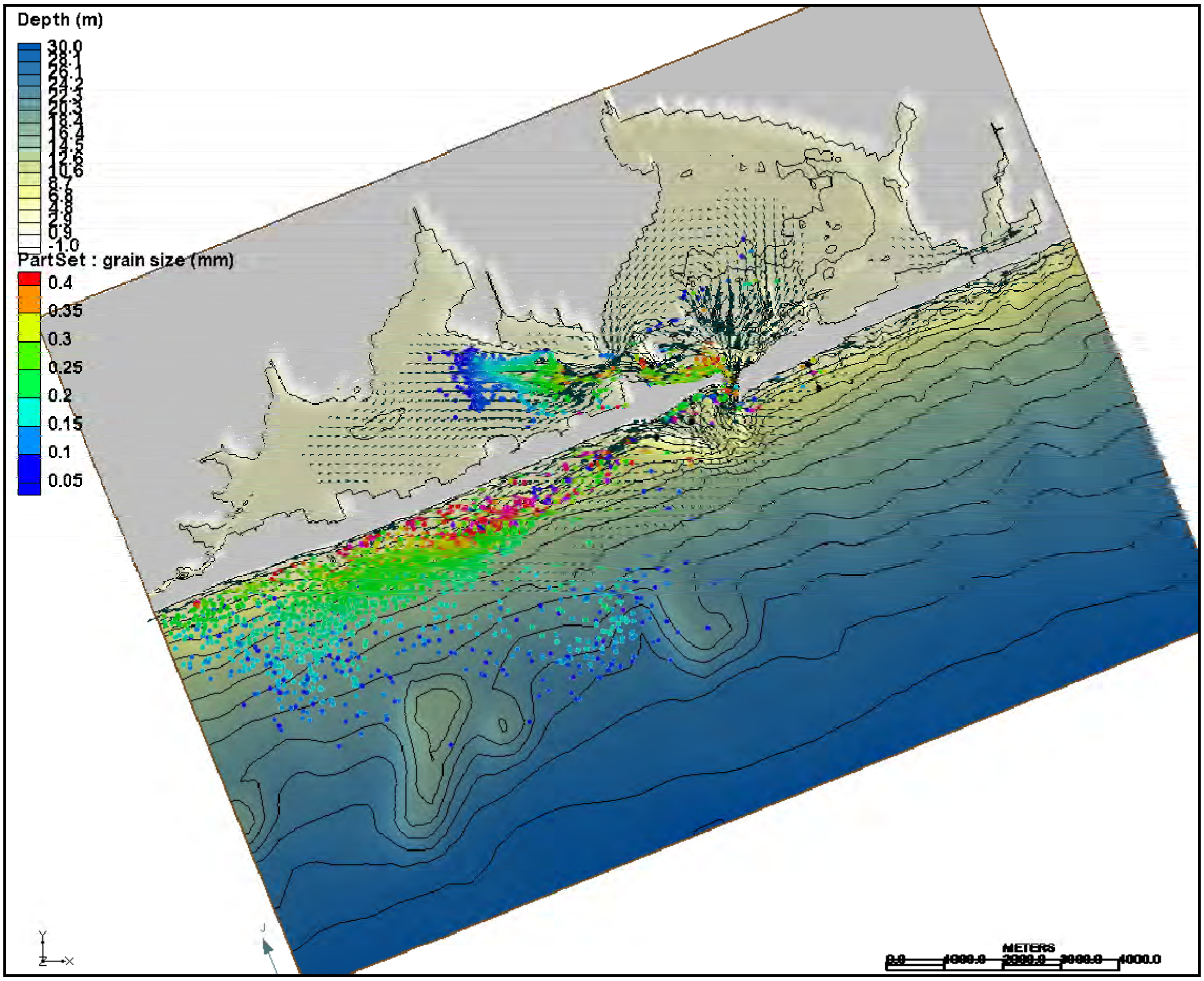


Figure 18. Distribution of particles 2.5 days after particle release for storm waves.

EXAMPLE 2: POPLAR ISLAND

The U.S. Army Engineer District, Baltimore (CENAB), in partnership with the Maryland Port Administration (MPA), is evaluating site development plans for construction and operation for filling and managing Poplar Island wetland cells. Poplar Island is a dredged material placement site and rebuilds a natural island in Chesapeake Bay that was eroded by waves and currents. The Maryland Environmental Service is assisting MPA and CENAB in the design and construction oversight for the island. As part of the site development plans, hydrodynamic modeling was conducted to evaluate tidal circulation patterns within the wetland cells. In addition, the hydrodynamic modeling can assess various channel geometries, as well as regions of potential scour and/or accretion. Figure 19 indicates the location of Poplar Island and marshes within the central region of Chesapeake Bay.

Figure 19. Location of Poplar Island within Chesapeake Bay (Example 2).

Example 2 is a CMS application for Poplar Island. In addition to repeating the steps described in Example 1 for the Poplar Island CMS hydrodynamic simulation, Example 2 familiarizes users with the calculation of residence time based on the coupled CMS-PTM. Because generic setup steps were covered in Example 1, only the steps applicable to Example 2 are given below.

1. Use Step 1 (reference Example 1) to load CMS simulation data. Load the CMS project Cell1A.sms simulation with its solution, as shown in Figure 20. The solution appears as data sets *Elev* and *Vel* in the tree under the CMS-Flow grid. Alternatively, open the Cell1A__CMS-Flow.cmcards file to load only the CMS-Flow simulation files.

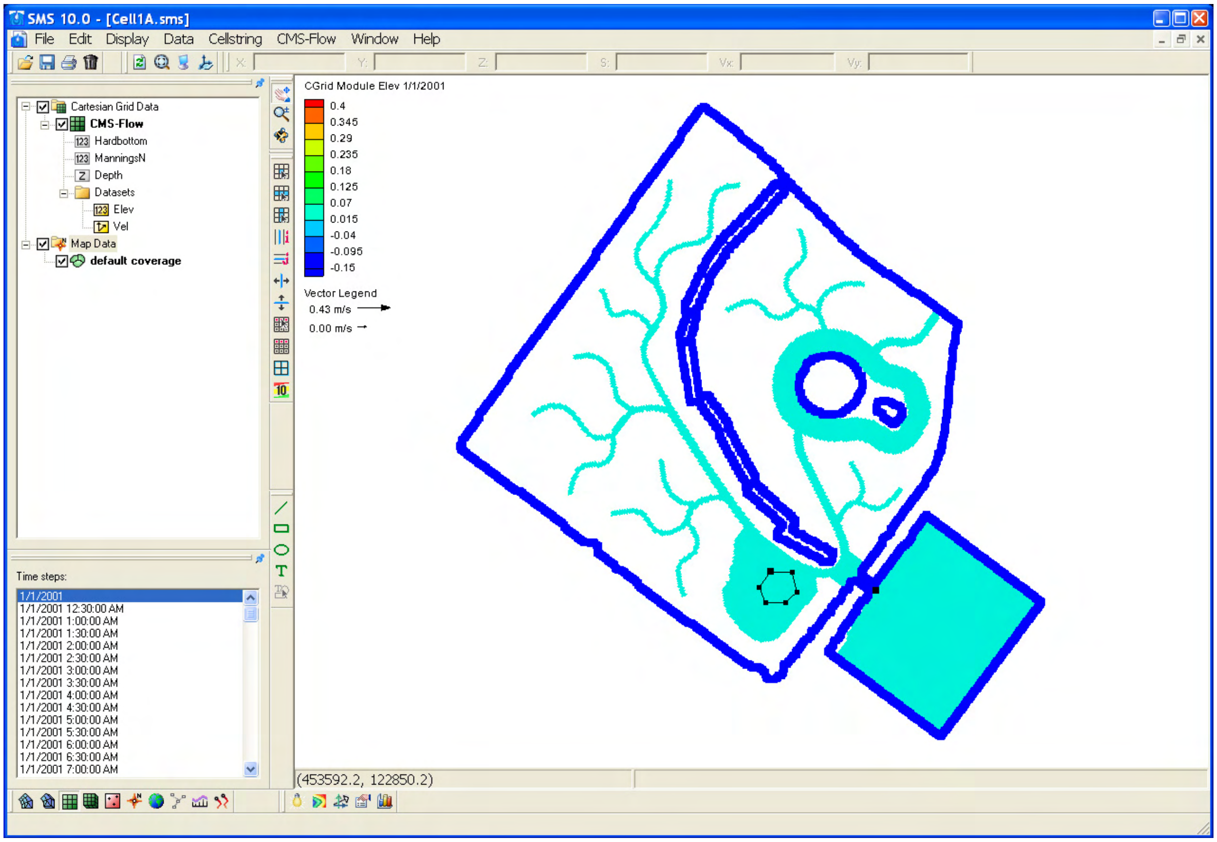


Figure 20. Loaded CMS Simulation for Poplar Island (Example 2).

2. Use Step 2 to generate native sediment data. After generating the PTM native bed sediment data (see Example 1 for steps to generate d35, d50, and d90), simulation data sets appear, as shown in Figure 21. Once these spatially constant data sets representing the sizes of the bed sediments are generated, the contours of the domain consist of a constant color. These data sets should be saved in a file named NativeSediments.h5.

3. Use Step 3 to generate the boundary conditions. For Example 2, the boundary condition cell strings already exist. The CMS model parameters do not need to be rewritten into the model parameters file.

4. Use Steps 4 and 5 to create PTM Model Control Data and file specifications. The next step is to create the new simulation. Open the PTM model control dialog and switch to the *Files* tab.

5. Use Step 6 to select mesh. The user was instructed (in the Example 1 description) to make sure the *Mesh* type was set to CMS-Flow (XMDF). Select the Cell1A__CMS-Flow_grid.h5 file and ensure the paths are correct.

6. Use Step 7 to select hydrodynamic files. Set the hydrodynamic file (Cell1A__CMS-Flow_sol.h5) along with the velocity and water surface paths, as for Example 1.

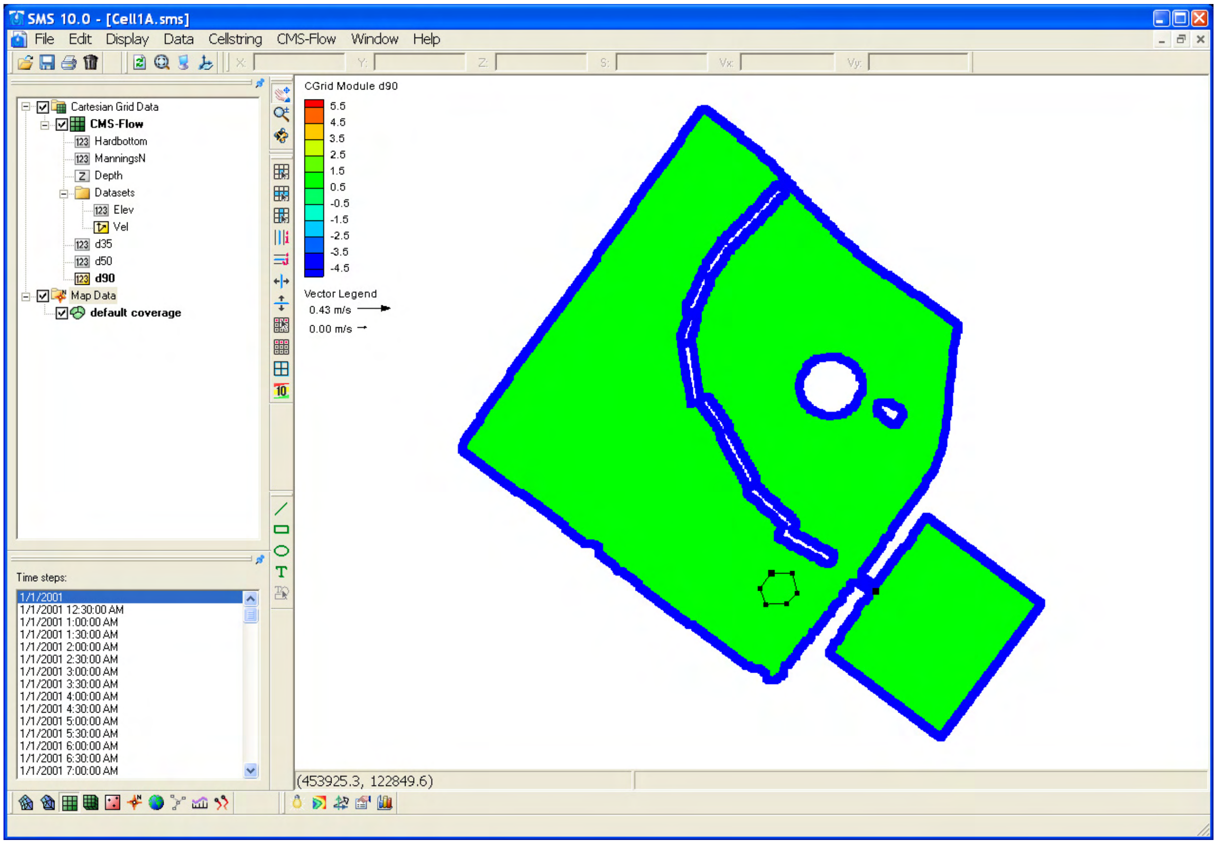


Figure 21. *Project Explorer* after creation of native sediments for Poplar Island (Example 2).

7. Use Step 8 for selecting boundary condition. Specify the boundary conditions file (Cell1A_CMS-Flow_mp.h5) to be used in the PTM simulation.

8. Use Step 9 for waves and breaking. Example 2 does not require waves in the Poplar Island cell, so this step is skipped.

9. Use Step 10 to select sediment source. In Example 2, an instantaneous mass point source was specified for the sediment source file. Set the *Options* column to *Existing file*, click the *Select file…* button in the *Filename* column, and choose the file Instant_0005.source. Selecting this file will cause SMS10 to open the file and create a coverage that includes the point source. A single source is specified at the entrance to the wetland cell. Its characteristics can be viewed and modified in a text editor by opening the source file.

The instantaneous mass source injected was specified as a point source and placed at the inlet (x = 453,959.62, y = 122,335.48, z = 0.65) (a surface source at water depth of 0.65 m). Individual particles from this source have a mass of 0.01 kg, and a total mass of 100 kg is introduced during the PTM simulation time. Particles are specified as fine grains having a mean diameter of 0.0005 mm sediment (clay). It was necessary to use this very small grain size because the flow over the wetland flats is weak. In Example 2, the velocity over the area where the trap is located reaches a maximum of only 2 cm/sec. The present version of PTM does not model a number of the processes that affect very fine non-cohesive and cohesive sediments (e.g.,

flocculation). Cohesive sediment capabilities will be added in a future version of the PTM. The distribution of sediments was set by selecting a standard deviation (0.8), which means the distribution of sediments is fairly broad and that there would be sediments both finer and coarser than 0.0005 mm. Although a small median grain size was selected, there will still be some deposition over the flats by this sediment during the simulation because of the weak flow field. Neutrally buoyant particles (same density as the fluid) are traditionally used in the estimate of residence times for salt and dissolved constituents. As done for this example, the user needs to decide an appropriate grain size for estimate of residence time when performing PTM simulations for fine-grain sand, silt, and clay sediments.

10. Use Step 11 for selecting neighbors. Specify a name for the neighbors file.

11. Use Step 12 for selecting native sediments. Select the native sediments file and paths.

12. Make trap selection. The trap is a user-defined polygon area (see the polygon in Figure 18) defined for calculation of residence time. The retention time of all particles within a trap (the shape, size, and location of which are defined by the user) represents the residence time. MacDonald et al. (2006) provide details about traps and residence-time calculation methods available in the PTM. Open traps in the PTM delineate an area, zone, or region. The time during which particles remain within a trap is the residence time (MacDonald et al. 2006; Demirbilek et al. 2005a, 2005b). In this simulation, a polygon trap, called a sediment trap, is specified (as shown in Figure 21) to determine how long fine-grained sediment would remain inside the user-defined polygonal region. Closed traps can be used for monitoring constituents, where particles are entrapped. The time that particles stay in a trap is representative of the residence time of particles crossing through a polygonal zone. The residence time is given in the PTM residence output file as the difference between the entrance and exit times of particles into or out of the polygonal zone. Residence time may be defined as the maximum, average, or minimum stay times of particles, depending on the process of interest. This requires users to select a trap they have defined in their files, set the trap option to *Existing file***,** click the *Select file…* button in the *Filename* column, and choose the file simple.trap**.** The assigned file name will cause SMS10 to open it, to create a coverage for the trap polygon.

13. Use Step 14 for Output Options. In the output options ((Figure 22), turn on the particle output for elevation, grain size, ID, mobility, or state. For additional information about the PTM output options, see Demirbilek et al. (2005a, 2005b) or MacDonald et al. (2006).

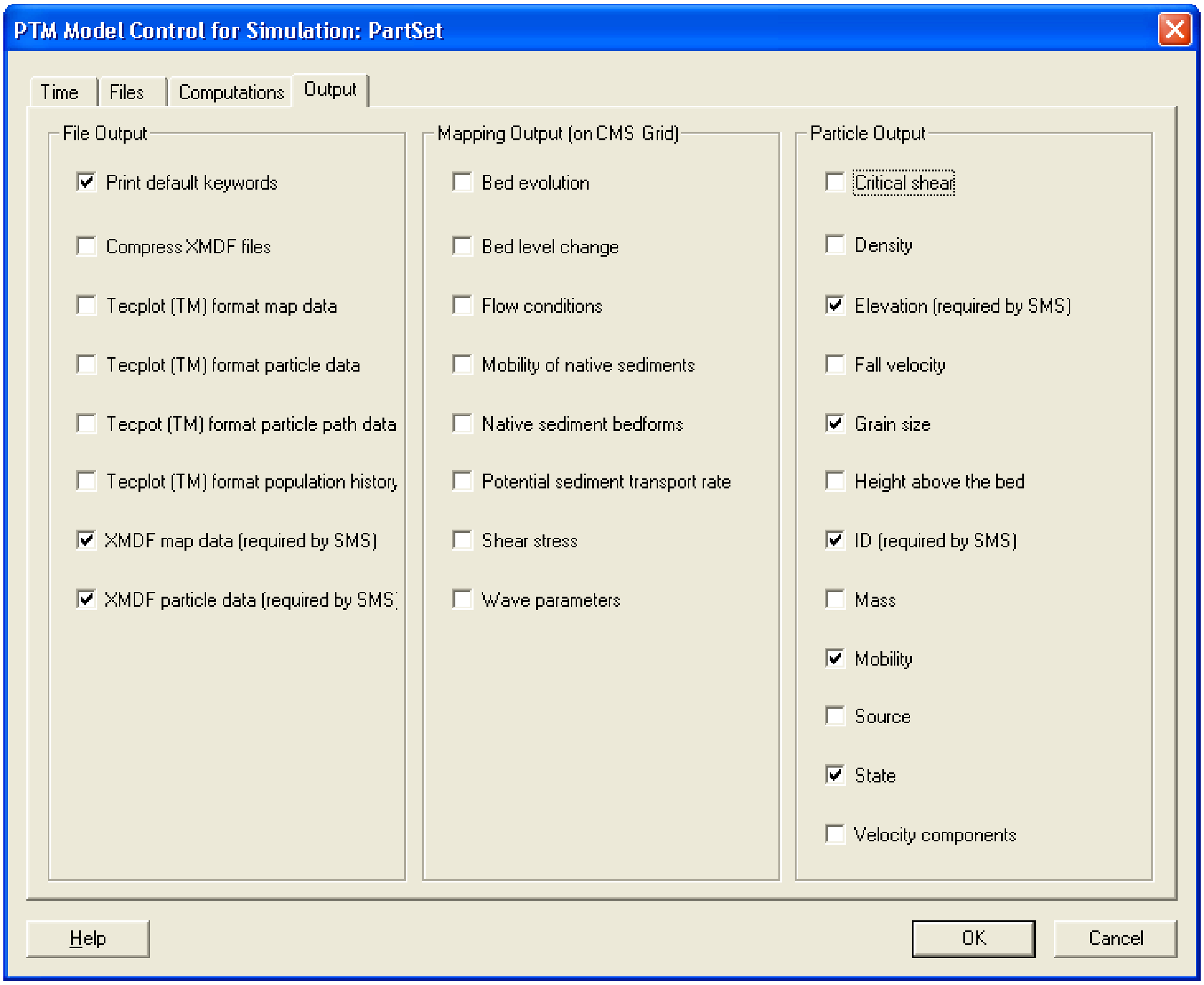


Figure 22. *Output* page of the *Model Control* for Example 2.

14. Use Step 15 for Time Options. For Example 2, set the *Time* page or tab entries of the *Model Control*, as shown in Figure 23. Note the trap has its own time range. The runtime for this PTM simulation is set to 36 hr.

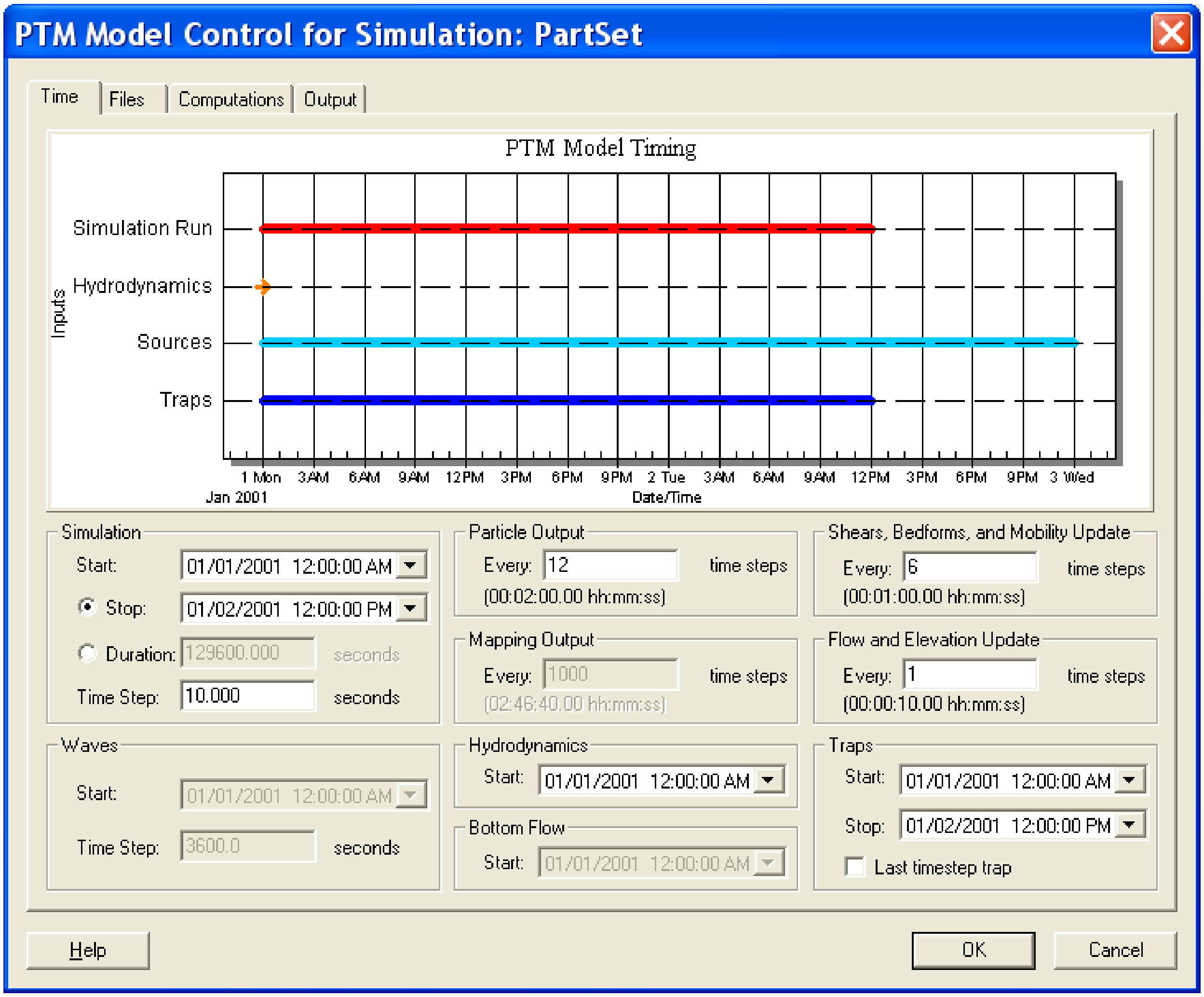


Figure 23. *Time* page of the *Model Control* for Example 2.

15. Use Step 16 to set Computation Options. Set the computations tab entries as shown in Figure 24. Note the *Residence* option has been enabled because we are interested in calculating residence time, and a polygon trap has been provided, as required.

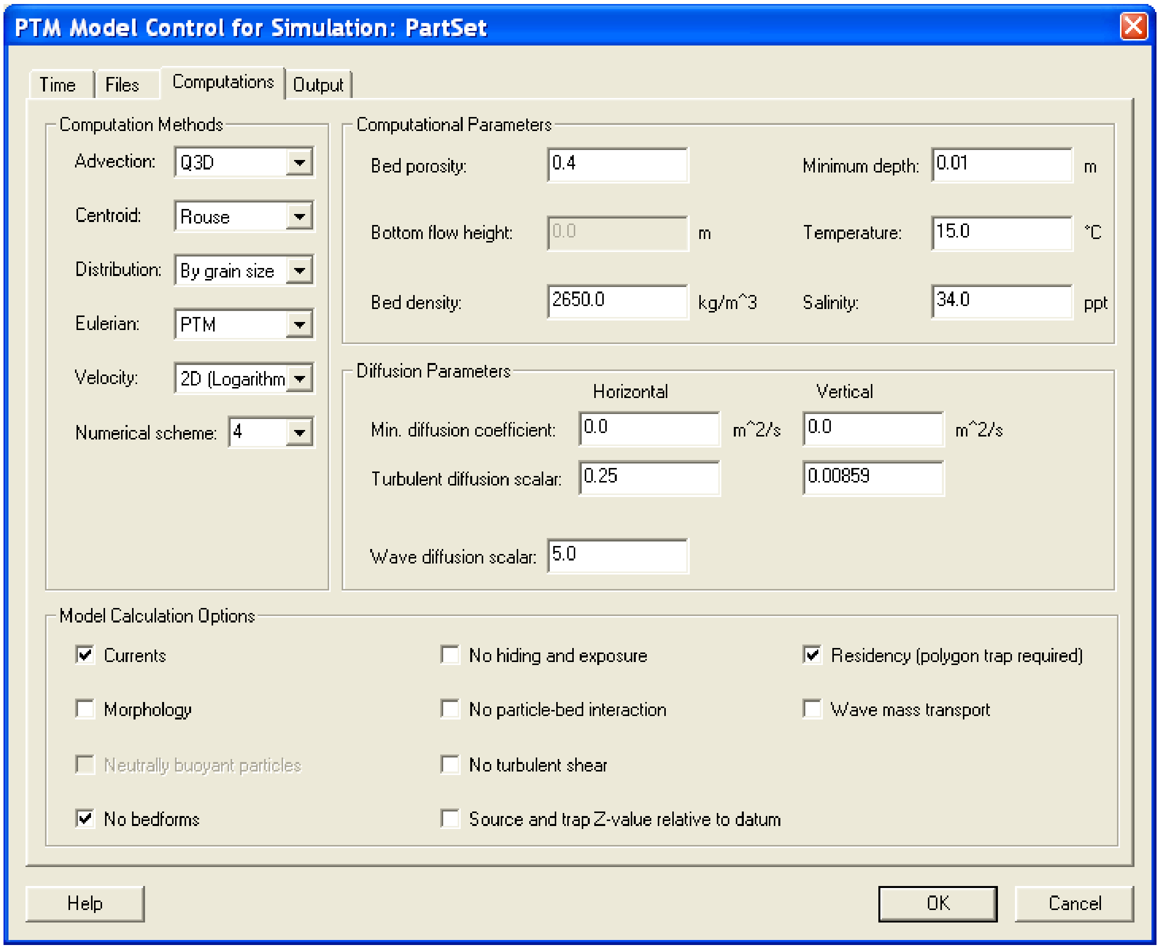


Figure 24. *Computations* page of the *Model Control* for Example 2.

16. Use Step 17 to Run the PTM. Now save the simulation and run the PTM. When the simulation is completed, the PTM creates a *_residency.out file. A few lines from a sample file are listed below to familiarize the user with the file content:

PARTICLES	AREA	TIME IN	TIME OUT	RESIDENCY (s)
1872	1	2001/01/01 02:23:20.0	2001/01/01 02:32:30.0	550.0
2644	1	2001/01/01 02:52:10.0	2001/01/01 02:59:10.0	420.0
2731	1	2001/01/01 02:55:20.0	2001/01/01 03:01:30.0	370.0
2846	1	2001/01/01 03:00:50.0	2001/01/01 03:06:30.0	340.0
2954	1	2001/01/01 03:02:40.0	2001/01/01 03:07:10.0	270.0
2966	1	2001/01/01 03:04:10.0	2001/01/01 03:08:30.0	260.0
2998	1	2001/01/01 03:05:20.0	2001/01/01 03:10:00.0	280.0
2983	1	2001/01/01 03:05:30.0	2001/01/01 03:10:20.0	290.0
3001	1	2001/01/01 03:05:30.0	2001/01/01 03:10:20.0	290.0
2989	1	2001/01/01 03:06:50.0	2001/01/01 03:11:40.0	290.0
3043	1	2001/01/01 03:08:50.0	2001/01/01 03:13:20.0	270.0
3075	1	2001/01/01 03:09:00.0	2001/01/01 03:13:30.0	270.0
3135	1	2001/01/01 03:11:00.0	2001/01/01 03:15:00.0	240.0
3145	1	2001/01/01 03:12:50.0	2001/01/01 03:17:10.0	260.0
3128	1	2001/01/01 03:11:50.0	2001/01/01 03:17:20.0	330.0
3175	1	2001/01/01 03:13:30.0	2001/01/01 03:18:00.0	270.0

3200	1	2001/01/01 03:15:00.0	2001/01/01 03:18:50.0	230.0
3215	1	2001/01/01 03:16:10.0	2001/01/01 03:20:20.0	250.0
3284	1	2001/01/01 03:18:20.0	2001/01/01 03:22:00.0	220.0
3291	1	2001/01/01 03:19:20.0	2001/01/01 03:23:40.0	260.0
3315	1	2001/01/01 03:20:10.0	2001/01/01 03:24:00.0	230.0
3342	1	2001/01/01 03:20:20.0	2001/01/01 03:24:10.0	230.0

The first column in the above listing shows the particle count, the second is the area ID, the third and fourth are the times that the particles enter and exit the trap, and the last column is the particle residence time. To obtain an estimate of particle residence time, the user can import the PTM output file (*_residency.out) into MS Excel® and calculate the average, maximum, minimum, median, standard deviation, and mode estimates of times for all particles passing through the trap. These calculations will be available within SMS10 in the next update. A sample of such calculations for the fine-grain PTM simulation for Example 2 is shown in Table 4.

Table 4
Residence time computations for fine-grain sediments (*d* = 0.0005 mm).

Count	1588					
Fraction	15.9%					
Average Time	3188.5	sec	53.1	min	0.89	hr
Minimum Time	20.0	sec	0.3	min	0.01	hr
Maximum Time	99850.0	sec	1664.2	min	27.74	hr
Median Time	1695.0	sec	28.3	min	0.47	hr
Standard Deviation	7654.1	sec	127.6	min	2.13	hr
Mode	1520.0	sec	25.3	min	0.42	hr

These estimates are dependent on the flow velocity, location of the trap, size of the trap, as well as type and duration of sediments specified. If the mean sediment diameter were changed to d = 0.05 mm (representing medium silt), the resultant estimates are as shown in Table 5.

Table 5
Residence time computations for fine-grain sediments (d = 0.05 mm).

Count	118					
Fraction	1.2%					
Average Time	32682.7	sec	544.7	min	9.08	hr
Minimum Time	20.0	sec	0.3	min	0.01	hr
Maximum Time	103810.0	sec	1730.2	min	28.84	hr
Median Time	2485.0	sec	41.4	min	0.69	hr
Standard Deviation	46030.3	sec	767.2	min	12.79	hr
Mode	102630.0	sec	1710.5	min	28.51	hr

The average particle residence time is almost 10 times as long as for the clay-sized particles. Residence time calculated in this manner may be related to sediment deposition within the trap.

The above estimates were based on PTM simulations in 2D mode, using fine-grain sediments as specified by the user. For details about the modes of PTM, see Davies et al. (2005) or MacDonald et al. (2006). In this mode, settling processes are modeled because particles can move vertically in the water column to the centroid of the local sediment transport distribution

(i.e., particles suspend or settle toward the centroid). The users could also make these estimates by selecting the neutrally buoyant particles option of the PTM. This option requires the PTM to be run in 3D mode. Because neutrally buoyant particles have no fall velocity, the 3D mode can be run with longer time steps. Results from such a run are listed in Table 6. A bar chart showing the comparison of residence time estimates by three methods is given in Figure 25. Various time estimates for fine-grain (d = 0.0005 mm) and neutrally buoyant particles are similar. The estimates for silt (d = 0.01 to 0.05 mm) are greater than those by two other methods. Because the present version of the PTM cannot accurately model processes controlling the behavior of very fine non-cohesive and cohesive particles, these estimates should be viewed with caution in project applications. The need for caution is evidenced by the large values of standard deviation reported in Figure 25, which are greater than the calculated average values. Residence time estimates for neutrally buoyant particles are considered reliable because they depend only on the flow and not on sediment properties.

Table 6
Residence time computations for neutrally buoyant particles.

Count	3335					
Fraction	33.4%					
Average Time	2291.5	sec	38.2	min	0.64	hr
Minimum Time	20.0	sec	0.3	min	0.01	hr
Maximum Time	14060.0	sec	234.3	min	3.91	hr
Median Time	2140.0	sec	35.7	min	0.59	hr
Standard Deviation	1891.4	sec	31.5	min	0.53	hr
Mode	360.0	sec	6.0	min	0.10	hr

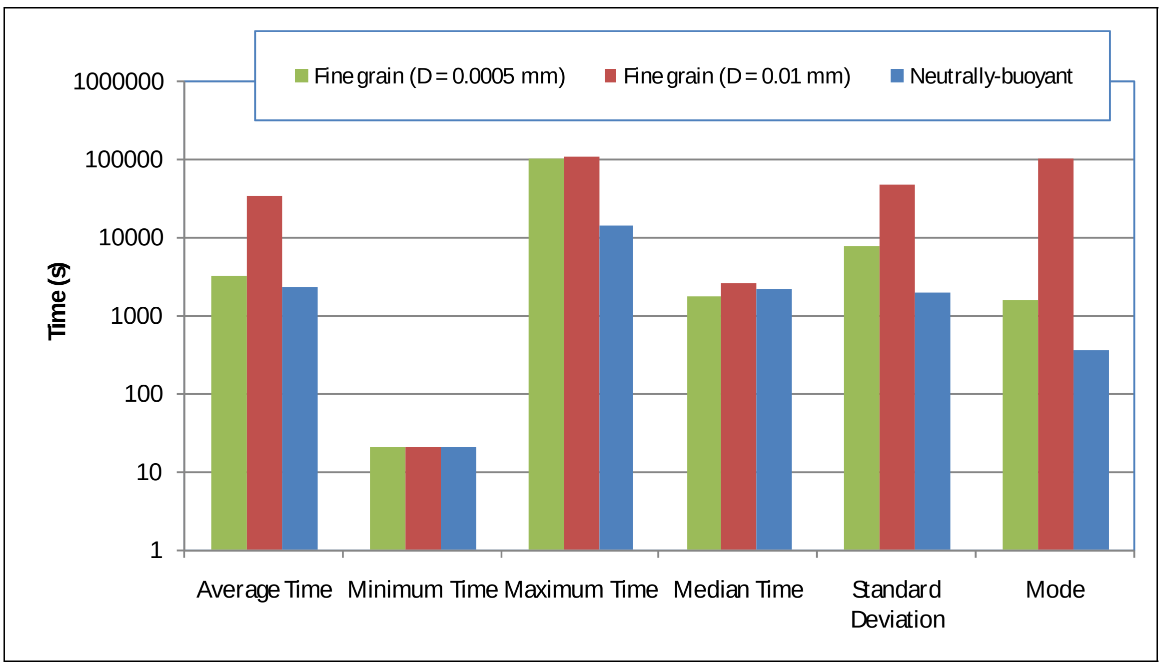


Figure 25. Comparison of residence time computations by three methods.

The statistics for the fine-grain cases are altered by particles that deposit within the trap. This process is illustrated in Figure 26, which shows the distribution of the residence time of the particles that enter the trap. Approximately 30 percent of the trapped particles in the silt-sized case remain in the trap for more than 100,000 sec (i.e., are deposited early in the simulation). The distribution of the residence times for the clay-sized particles and the neutrally buoyant particles is similar.

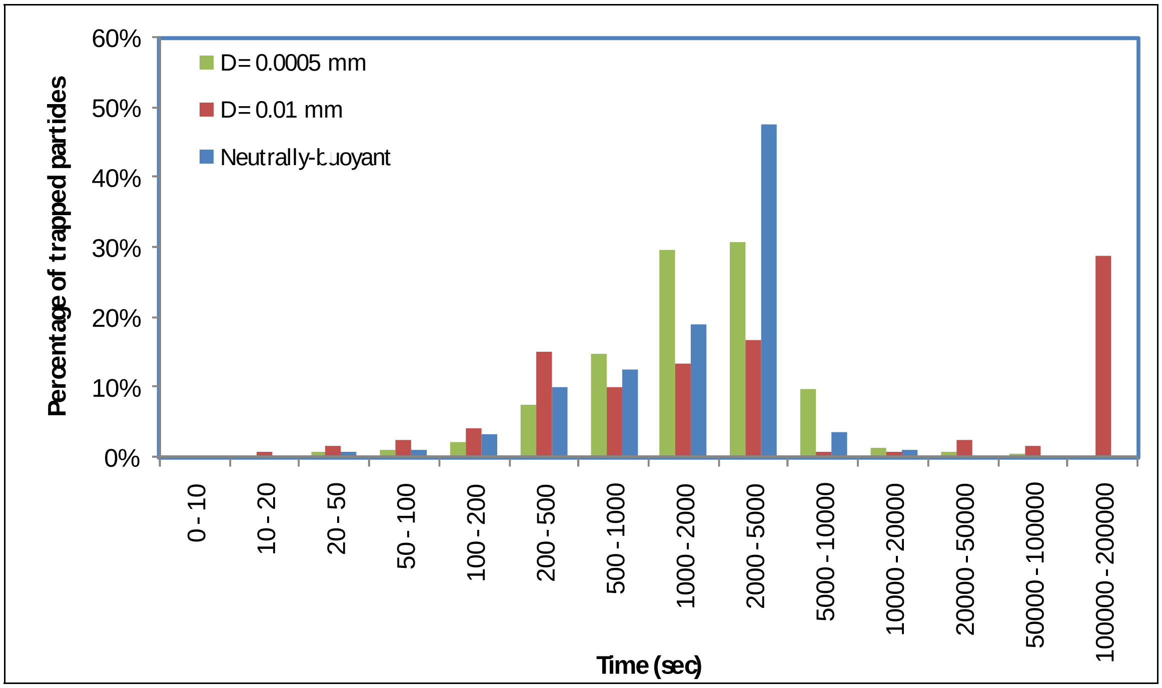


Figure 26. Distribution of particle residence times by three calculation methods.

In a general sense, estimates of particle residence times can vary both with the type of flow and the PTM running mode selected. In addition, these estimates can change by including and excluding particles that could skew the calculations. A sensitivity study may be necessary to arrive at a well-understood estimate for the particular application depending on geometry, forcing condition (flow and waves), and also distribution of sediment sources specified. The PTM is a computationally fast and insightful tool to examine response of sediment particles to complex marine environments. Driven by hydrodynamics from circulation models such as CMS-Flow and wave models such as CMS-Wave, the PTM can identify areas of sediment mobility and deposition and can predict sediment transport pathways in coastal projects.

ADDITIONAL INFORMATION: This CHETN was prepared as part of the Coastal Inlets Research Program (CIRP) and was written by Dr. Zeki Demirbilek (Zeki.Demirbilek@usace.army.mil, voice: 601-634-2834, fax: 601-634-3433) and Kenneth J. Connell (Kenneth.J.Connell@usace.army.mil) of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), along with Dr. Neil MacDonald of Coldwater Consulting, Ltd. (nmacdonald@coldwater-consulting.com), and Dr. Alan Zundel (azundel@aquaveo.com) of Brigham Young University. Dr. Lihwa Lin and Alejandro Sanchez, CHL, furnished information for the CMS-Wave and Poplar Island examples. The CIRP Program Manager, Dr. Nicholas C. Kraus (Nicholas.C.Kraus@usace.army.mil),

reviewed this CHETN. Files for the examples may be downloaded from http://xmswiki.com/. This CHETN should be cited as follows:

> Demirbilek, Z., K. J. Connell, N. J. MacDonald, and A. K. Zundel. 2008. *Particle Tracking Model in the SMS10: IV. Link to Coastal Modeling System*. Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-IV-71. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://chl.erdc.usace.army.mil/chetn.

REFERENCES

Buonaiuto, F. S., and H. J. Bokuniewicz. 2008. Hydrodynamic partitioning of a mixed energy tidal inlet. *Journal of Coastal Research* 24(4):344–353.

Buonaiuto, F. S., and A. Militello. 2004. Coupled circulation, wave, and morphology-change modeling, Shinnecock Inlet, New York. In *Proceedings, 8th Conference on Estuarine and Coastal Modeling*, 819–838. New York: American Society of Civil Engineers.

Buttolph, A. M., C. W. Reed, N. C. Kraus, N. Ono, M. Larson, B. Camenen, H. Hanson, T. Wamsley, and A. K. Zundel. 2006. *Two-dimensional depth-averaged circulation model CMS-M2D: Version 3.0; Report 2: Sediment transport and morphology change*. ERDC/CHL TR-06-7. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Davies, M. H., N. J. MacDonald, Z. Demirbilek, S. J. Smith, A. K. Zundel, and R. D. Jones. 2005. *Particle Tracking Model (PTM): II. Overview of features and capabilities*. *Dredging Operations and Environmental Research Technical Notes Collection* (ERDC TN-DOER-D5). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Demirbilek, Z., J. Smith, A. K. Zundel, R. Jones, N. MacDonald, and M. Davies. 2005a. *Particle Tracking Model (PTM) in the SMS: I. Graphical interface*. *Dredging Operations and Environmental Research Technical Notes Collection* (ERDC TN-DOER-D4). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Demirbilek, Z., J. Smith, A. Zundel, R. Jones, N., MacDonald, and M. Davies. 2005b. *Particle Tracking Model (PTM) in the SMS: III. Tutorial with examples*. *Dredging Operations and Environmental Research Technical Notes Collection* (ERDC TN-DOER-D6). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Demirbilek, Z., L. Lin, and A. Zundel. 2007. *WABED model in the SMS: Part 2. Graphical interface*. *Coastal and Hydraulics Engineering Technical Note* ERDC/CHL CHETN-I-74. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Jones, N. L., R. D. Jones, C. D. Butler, and R. M. Wallace. 2004. A generic format for multi-dimensional models. In *Proceedings, World Water and Environmental Resources Congress 2004.* http://www.pubs.asce.org/WWWdisplay.cgi?0410405.

Kana, T. W. 1995. A mesoscale sediment budget for Long Island, New York. *Marine Geology* 126:87–110.

Lin, L., H. Mase, F. Yamada, and Z. Demirbilek. 2006. *Wave-action balance equation diffraction (WABED) model: Tests of wave diffraction and reflection at inlets*. *Coastal and Hydraulics Engineering Technical Note* ERDC/CHL CHETN-III-73. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

MacDonald, N. J., M. H. Davies, A. K. Zundel, J. D. Howlett, T. C. Lackey, Z. Demirbilek, and J. Z. Gailani. 2006. *PTM: Particle tracking Model; Report 1: Model theory, implementation, and example applications*. ERDC/CHL TR-06-20. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Mase, H. 2001. Multidirectional random wave transformation model based on energy balance equation. *Coastal Engineering Journal* 43(4):317–337.

Mase, H., K. Oki, T. S. Hedges, and H. J. Li. 2005. Extended energy-balance-equation wave model for multidirectional random wave transformation. *Ocean Engineering* 32(8-9):961–985.

Militello, A., and S. A. Hughes. 2000. *Circulation patterns at tidal inlets with jetties*. Coastal Engineering Technical Note ERDC/CHL CETN-IV-29. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Militello, A., and N. C. Kraus. 2001a. *Shinnecock Inlet, New York, site investigation; Report 4, Evaluation of flood and ebb shoal sediment source alternatives for the west of Shinnecock Interim Project, New York*. ERDC/CHL TR-98-32. Vicksburg, MS: U. S. Army Engineer Research and Development Center.

Militello, A., and N. C. Kraus. 2001b. Re-Alignment of an inlet entrance channel by ebb-tidal eddies. In *Proceedings, Coastal Dynamics '01*, 423–432. New York: American Society of Civil Engineers.

Militello, A., N. C. Kraus, and M. E. Brown. 2000. Regional coastal and inlet circulation modeling with application to Long Island, New York. In *Proceedings, 13th Annual National Beach Preservation Technology Conference*, 191–201. Tallahassee, FL: Florida Shore and Beach Preservation Association.

Militello, A., N. C. Kraus, D. S. Rahoy, S. Couch, and P. M. Weppler. 2001. Establishment of a flood shoal sand source with preservation of existing habitat function. In *Proceedings, 14th Annual National Beach Preservation Technology Conference*, 327–341. Tallahassee, FL: Florida Shore and Beach Preservation Association.

Militello, A., C. W. Reed, A. K. Zundel, and N. C. Kraus. 2004. *Two-dimensional depth-averaged circulation model CMS-M2D: Version 2.0; Report 1: Technical documentation and user's guide*. ERDC/CHL TR-04-02. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Morang, A. 1999. *Shinnecock Inlet, New York, site investigation; Report 1: Morphology and historical behavior*. Technical Report CHL-98-32. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Panuzio, F. L. 1968. The Atlantic coast of Long Island. In *Proceedings, 11th Conference on Coastal Engineering*, 1222–1241. New York: American Society of Civil Engineers.

Pratt, T. C., and D. K. Stauble. 2001. *Selected field collection efforts at Shinnecock Inlet, New York; Report 3: Selected field data report for 1997, 1998, 1999, velocity and sediment surveys*. Technical Report CHL-98-32. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Williams, G. L., A. Morang, and L. Lillycrop. 1998. *Shinnecock Inlet, New York, site investigation; Report 2, Evaluation of sand bypass options*. Technical Report CHL-98-32. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Zundel, A. K. 2007. *Surface-water modeling system reference manual, Version 10.0*. Provo, UT: Brigham Young University Environmental Modeling Research Laboratory. http://www.ems-i.com/SMS/SMS_Overview/sms_overview.html.

Zundel, A. K., A. L. Fugal, N. L. Jones, and Z. Demirbilek. 1998. Automatic definition of two-dimensional coastal finite element domains. In *Proceedings, Hydroinformatics 98*, ed. V. Babovic and L. C. Larsen, 693-700. Rotterdam: A. A. Balkema.